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WORKSHOP ON:

UNREGULATED DIESEL EMISSIONS AND THEIR POTENTIAL HEALTH EFFECTS

EDITED TRANSCRIPT OF PROCEEDINGS

APRIL 27-28, 1978

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NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

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16. Abstract

With the advent of the fleet average fuel economy standards for passenger cars and light trucks, the international passenger car and truck manufacturers have sought cost effective means of improving fuel economy. The dieselization of the passenger car and light truck fleets is a singularly important way to improve fuel economy. With the many unknowns concerning unregulated diesel emissions and their potential impact on human health, the responsible government agencies, NHTSA, DOE, and EPA, have taken a cautious attitude regarding a major shift into diesel engines until more is learned. All three agencies have been actively studying the problems of diesel emission measurement, control, dispersion, and chemical transformation and medical effects.

This workshop, which had extensive participation from industry, universities, government agencies, and concerned citizens, provided an opportunity to exchange information among experts, policy makers, and interested parties in the areas of: (1) emissions characterization and measurement; (2) control technology; (3) factors affecting human exposure; and (4) health effects. As the proceedings show, there is much to be learned about unregulated diesel emissions.

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PREFACE

With the advent of the fleet average fuel economy standards for passenger cars and light trucks, the international passenger car and truck manufacturers have sought cost effective means of improving fuel economy. The dieselization of the passenger car and light truck fleets is a singularly important way to improve fuel economy

With the many unknowns concerning unregulated diesel emissions and their potential impact on human health, the responsible government agencies, NHTSA, EPA, and DOE have taken a cautious attitude regarding a major shift into diesel engines until more is learned. NHTSA has acted by establishing fuel economy standards at levels that do not require the use of diesel engines. At the same time, manufacturers have acted to use diesel engines to improve economy, with aggressive programs underway at GM, VW and other companies. EPA, DOE, and NHTSA have been actively studying the problems of measurement, control, dispersion, and chemical transformation and medical effects.

This workshop, the complete proceedings of which are attached, represents an important milestone. The three principal agencies concerned with this subject, NHTSA, EPA, and DOE, have sponsored this workshop and have invited and received participation from industry, universities, other government agencies, and concerned citizens. As the proceedings will show, there is much to be learned about unregulated diesel emissions; and there is much to be gained by workshops such as this that allow for the constructive exchange of ideas.

We gratefully acknowledge the contributions of those who made the presentations contained in this document and of those who participated in each of the four panel discussions and, especially, to the chairman of each of the four sessions.

Samuel F. Powel III

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PROCEEDINGS

MR. POWEL: Good morning ladies and gentlemen, and welcome to the Workshop on the Unregulated Diesel Emissions and Their Potential Health Effects sponsored by the National Highway Traffic Safety Administration, the Department of Energy, and the Environmental Protection Agency.

I am Sam Powel, Acting Chief of the Technology Assessment Division, Office of Passenger Vehicle Research, Associate Administrator of Research and Development, which has cognizance over the research and development aspects of this work for NHTSA.

First, I must apologize for the short notice that you have had in getting together for this meeting and thank you for your excellent response, which speaks for your strong interest in the problem of diesel emissions.

In scanning the agenda for the Workshop, it is apparent that we will have a great deal of information presented at this meeting which will contribute to our current understanding of the problem, which is the purpose of this Workshop this morning.

We have divided our discussions for this Workshop into four sessions which will include presentations and panel discussions. Section A, Emissions Characterization and Measurement, will be chaired by Dr. John Johnson of Michigan Technological University.

Section B, Control Technology, will be chaired by Mr. Richard W. Hurn of the Department of Energy.

Section C, Factors Affecting Human Exposure, will be chaired by Dr. Alan J. Grobecker, National Science Foundation.

Section D, Health Effects, will be chaired by Dr. Thomas Milby, Environmental Health Associates, Inc.

The Workshop Chairman will be Richard L. Strombotne, Director, Office of AutomotiveeFuel Economy Standards, National Highway Traffic Safety Administration.

The presentations and panel discussions given at this Workshop will be recorded. However, if participants care to talk off the record, they can do so if they so desire and if they will so indicate when they get up to talk.

A verbatim transcript of the proceedings will be provided to each presenter and panelist for correction after the Workshop, and the corrected transcript will be provided to each registrant and other interested parties after the Workshop. This document will represent NHTSA's current knowledge of the diesel emissions problem at this time.

There are a few procedural matters I would like to take care of at this time. Presentations will be given in the order listed on the program. Presenters, please deliver vugraphs and slides to the machines here in front if they are going to use them in their presentations. We will set them up in order and operate the machines.

Please do that about 30 minutes before the sessions. There may be some delay on the first session for the first few presentations. We would like to have a hard copy of the vugraphs and slides for each presentation to be delivered to Mr. Siegel, South Coast Technology, Inc., who will include them for the record. If you did not bring a hard copy with you, we would like to have your slides. We will copy them and return them to you as soon as we can.

On Friday morning at 9 o'clock, tomorrow, Miss Claybrook, Administrator of National Highway Traffic Safety Administration, and Mr. Hawkins, Assistant Administrator for Air and Waste Management, Environmental Protection Ageneyy, will be present at the meeting to give their views on the diesel emissions problem; and now, I would like to introduce Dr. Richard L. Strombotne, Acting Director, Office of Automotive Fuel Economy Standards, National Highway Traffic Safety Administration.

DR. STROMBOTNE: Thank you, Sam. I want to welcome all of you on behalf of Administrator Claybrook and our colleagues from the Department of Energy and from the Environmental Protection Agency, and I would like to give you some background on the issue as we saw it and how this Workshop came about.

Last summer, Secretary Adams issued the fuel economy standards for model year 1981 through 1984 passenger automobiles. At that time, he set the levels of the standards such that, in our view, it would not be necessary to use diesel engines to meet the standards. He did so for a number of reasons, and I won't go through all of them; but I would like to say that one of them was concern about possible adverse health effects of diesel engines.

About August last year, Miss Claybrook sent a letter to Administrator Costle, asking for the assistance of the Environmental Protection Agency in assessing what the consequences of expanded use of diesel engines might be in the long term; and I would like to go through some estimates and calculations for three cases that were described to the Environmental Protection Agency for their consideration in examining the environmental consequences.

Could I have the first vugraph? #1

This is simply a display of percentage penetration into the new light duty vehicle fleet by model year to about the year 2000, and you can see it is very simple. Case one is a linear increase in diesel engines in the new vehicle fleet from zero in 1980 to 25 percent in 1985, and then stays constant from that time forward.

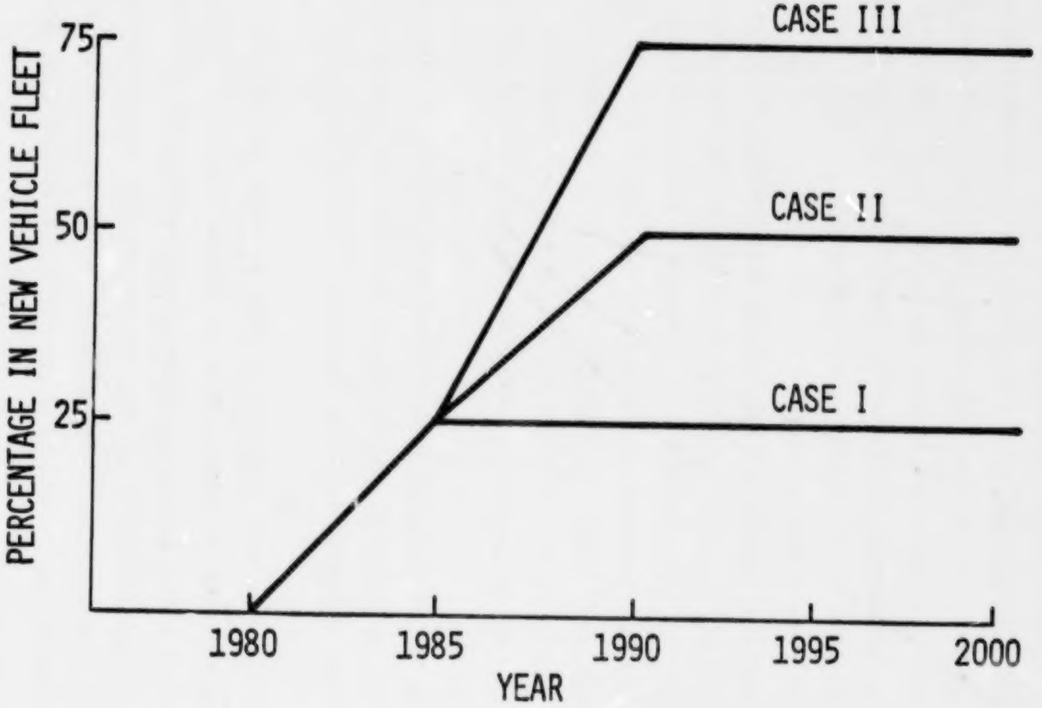
Case two indicates a continuation of the rate of increase until 1990, where the percentage penetration reaches 50 percent and stays at that level.

Case three is an expanded penetration case where the rate of increase jumps by a factor of two so that, by 1990, the extent of penetration in the new vehicle fleet reaches 75 percent and stays at that level.

If I may have the next vugraph, I want to show you why we think #2
this kind of penetration or application of diesel engines is particularly valuable for the nation in terms of conserving energy. We have done some rough estimates of the energy savings associated with expanded use of diesel engines for passenger automobiles where the usage would be above the 27-1/2 mile per gallon standard that goes

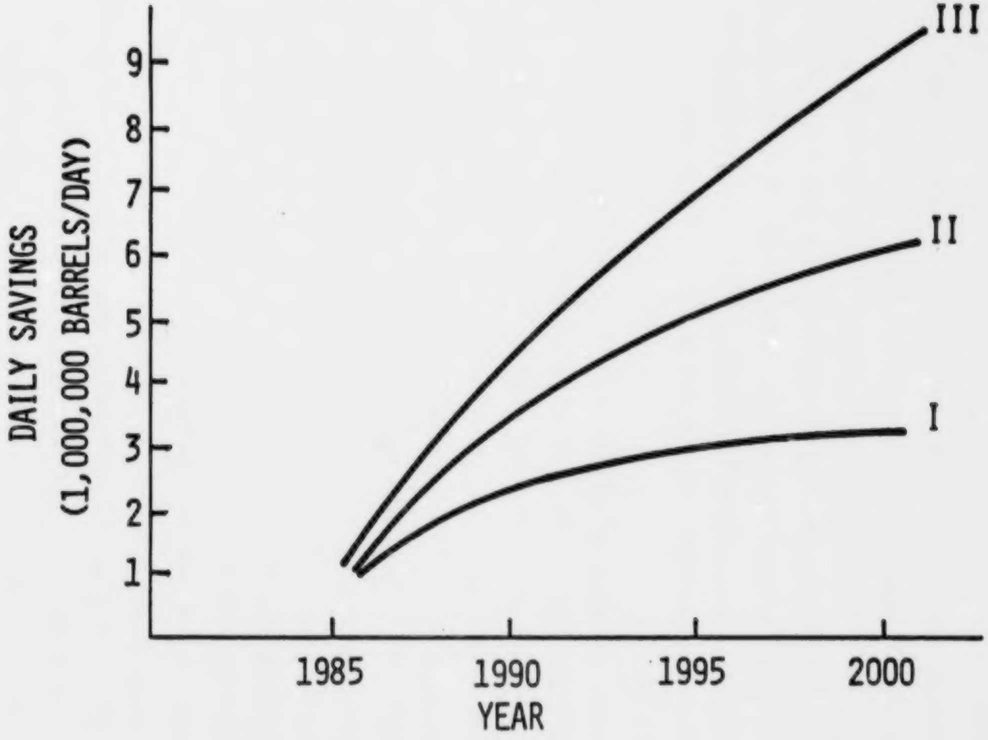
#1

THREE CASES OF SHARE OF DIESELS
IN NEW LIGHT DUTY VEHICLE FLEET BY YEAR



#2

DAILY FUEL SAVINGS DUE TO DIESELS IN NEW LDV FLEET



(For PA & LDT Combined ~ 14 M Veh/Yr
27.5 PA, 17.2 Augumented)

into effect in model year 1985 and a realistic scenario for the fuel economy of light duty trucks.

Now, the case one curve shows that the fuel savings throughout the 90's is roughly in the range of 300,000 barrels per day.

By the year 2000 in case three, the energy savings reaches 900,000 barrels per day. Another view of the same analysis gives the cumulative savings, and that is the next vugraph, which I would like to show now. #3

Again, keeping the three cases in mind, by the year 2000, the total savings would be approximately 1-1/2 billion barrels.

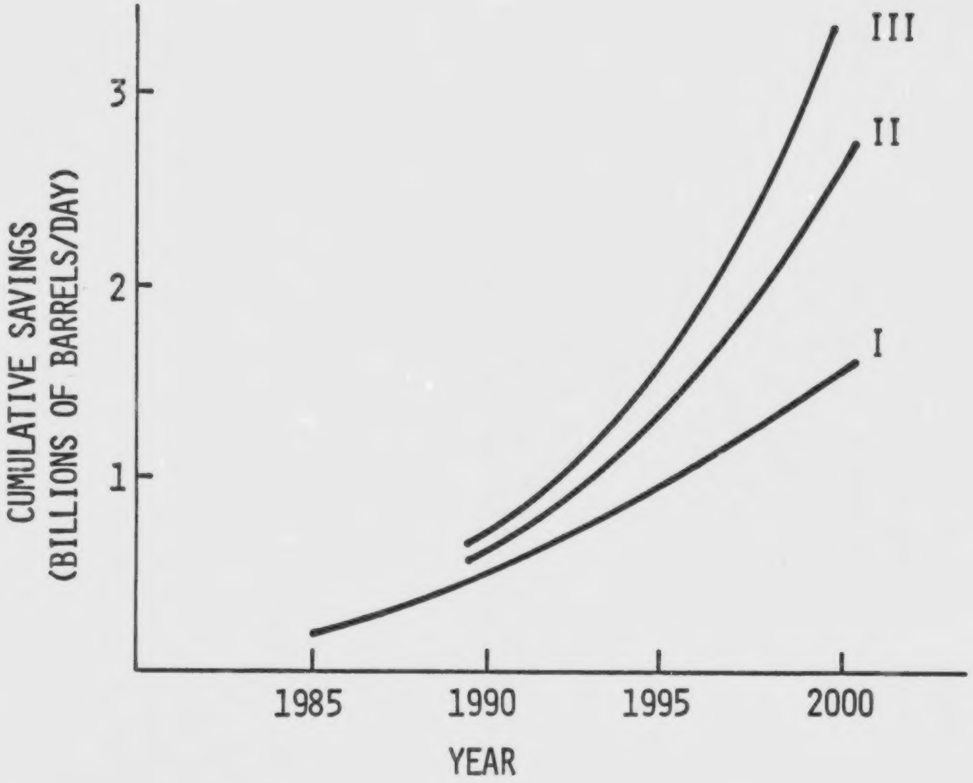
For case three, the savings would be approximately 3-1/3 billion barrels, and for reference, you might remember that the North Slope oilfield is estimated to have reserves of approximately 10 billion barrels. So, in case three, we are talking about 1/3 of the Alaska North Slope oil field reserves, and in case one, 1/2 of that, of one-sixth fraction.

By the fall, a number of things had happened. The Environmental Protection Agency had initiated some work to examine the health effects of diesel engines. You will hear more about that in the sessions to come, and I won't go into any details. A workshop was held at the Transportation Systems Center to explore some of the work going on in diesel engines. This was primarily a workshop of government people describing the work that they had going on; and then, in January of this year, Miss Claybrook and some of her staff met with Dr. Gage and Mr. Hawkins at the Environmental Protection Agency to review this issue, to go over some of the health effects research that was coming out of the Environmental Protection Agency; and it became quite evident to all of them that it was important to get on top of the diesel engine emissions issue in fairly short order.

Following that meeting, representatives of the Department of Transportation and the Environmental Protection Agency initiated discussions with representatives of the Department of Energy to alert them as to what was happening and to instigate further discussions on a coordinated program.

#3

CUMULATIVE FUEL SAVINGS
DUE TO DIESELS IN NEW LDV FLEET



Now, the purpose of the Workshop today, for these next two days is to look at the problems and solutions of diesel engine emissions together.

As you notice from the organization of the sessions, the sessions are to look at the characterization and measurement of diesel engine emissions; then to go on and consider the status of emission control technology, the knowledge or, in some cases, the lack of knowledge about control technology and efficacy; tomorrow morning, to consider some of the factors that affect human exposure, including the dispersion models, total mass emissions, comparison with other sources of particulates; and then, tomorrow afternoon, to examine some of the health effects issue.

You are all here today either at invitation or because you have found out by word of mouth of the meeting. We are very happy that all of you are able to be here.

You are most welcome, and we appreciate very much the efforts that you have made to be here and to participate; and I would now like to turn the meeting over to Professor John Johnson from Michigan Technological University who will be the Chairman of the first session.

PROF. JOHNSON: It is indeed a pleasure to be Chairman of this particular session. We are going to examine the emissions characterization and measurement. As all of you can see on the program, I am going to have a tough job running this meeting because of the number of papers that we have to present this morning and the idea that we want to have a panel discussion at the end.

First of all, I would like to just give a little bit of an overview of how we are going to conduct the session so that you have a little bit of a feeling of where you can get your questions in and what the overall thrust of the session is.

What we would like to do is to go through all the papers. Because there are nine papers today, plus the panel, we would like to have you hold your questions until the panel discussion. It is my hope that most of the speakers can limit their time to 15 or, at the most, 20 minutes. We will get the panel up here after the papers, and then we will throw the floor open for questions about the various papers, presentations, or just general questions in the area of emissions characterization and measurement.

The diesel, obviously, is a very attractive powerplant, as we have seen here, for fuel economy. For a long time, my experience has been in the heavy duty end of the business; and, obviously, the main thrust is to talk about the light duty problem; but there is a lot of technology, a lot of measurements, and a lot of information that is available and extrapolatable from the heavy duty problem, but for a long time it has been known that odor and the particulate, or what probably most of the development engineers would have normally called smoke emissions. The industry has obviously worked hard to improve on these two characteristics over the years.

The question of fuel economy has obviously raised the need to look at dieselization, and we have an SAE paper that we are presenting this June on some of our modelling work of the truck market in terms of computing fuel usage and emissions; and, very clearly from our survey of the manufacturers, people that build engines and vehicles in the truck market, there is underway an increased dieselization in the heavy duty end, the medium duty, and obviously in the light duty and also in the car. There is very much interest in terms of dieselization. E

Even though the main thrust of this first session, Section A, is going to look at the engine in the laboratory, in terms of organizing the overall two-day Workshop, it seemed appropriate that we take a look at the bigger system, the whole environment from a broad aspect. So, the first paper, entitled "An Overview on Diesel Exhaust and Air Quality: Chemical Implications," authored by Dr. Jim Pitts, Dr. Arthur Winer, and Karl Van Cauwenberghe, will be presented by Dr. Pitts.

AN OVERVIEW ON DIESEL EXHAUST AND AIR QUALITY:
CHEMICAL IMPLICATIONS

by

James N. Pitts, Jr., Arthur M. Winer and Karel A. Van Cauwenberghe
Statewide Air Pollution Research Center
University of California
Riverside, CA 92521

Two of the key components of unregulated diesel emissions are oxides of nitrogen and organic particulates. In the past we have tended to examine more carefully the so-called "criteria pollutants" such as NO_2 since these are the species for which, by law, air quality criteria documents were developed and air quality standards set. However, non-criteria pollutants such as organic particulates are now of increasing concern, since many researchers believe they may have serious health effects that are out of proportion to the relatively small amounts that may be present in polluted atmospheres.

Such concern was shown by Congress and by the President when they signed into law the Clean Air Act Amendments of 1977. Slide 1 summarizes, shall we say, the "rules of the game." Thus, Section 104B of the Amendments requires the Administrator of the EPA to review and develop information on--and these are non-criteria pollutants--nitric and nitrous acids, nitrites, nitrates, nitrosamines and other carcinogenic and potentially carcinogenic derivatives of oxides of nitrogen.

Another section requires the Administrator to determine "whether or not emissions of polycyclic organic matter, POM, into ambient air will cause, or contribute to, air pollution which may reasonably be anticipated to endanger public health." It is in this context, that is of Public Law 95-95, that we here today must deal with these issues.

AMENDMENTS TO THE CLEAN AIR ACT

AUGUST 1977

SECTION 104b: REQUIRES THE ADMINISTRATOR OF THE ENVIRONMENTAL PROTECTION AGENCY (EPA) TO REVIEW AND CRITIQUE ALL AVAILABLE INFORMATION ON "NITRIC AND NITROUS ACIDS, NITRITES, NITRATES, NITROSAMINES AND OTHER CARCINOGENIC AND POTENTIALLY CARCINOGENIC DERIVATIVES OF OXIDES OF NITROGEN."

SECTION 122(a): REQUIRES THE ADMINISTRATOR TO "DETERMINE WHETHER OR NOT EMISSIONS OF POLYCYCLIC ORGANIC MATTER (POM) INTO THE AMBIENT AIR WILL CAUSE, OR CONTRIBUTE TO AIR POLLUTION WHICH MAY REASONABLY BE ANTICIPATED TO ENDANGER PUBLIC HEALTH "

Slide 1

This charge of Congress to the Administrator of EPA poses a variety of difficult scientific problems. First of all, to establish accurately the nature and magnitude of a health effect, obviously one must have reliable dose-response curves. In this respect, in our laboratory as atmospheric scientists our inputs are to the "dose" variable, not the "response" parameter. In short, our job is to establish the dose for the pollutants in question. To do this we must have a detailed knowledge of the physical and chemical states of the compounds present in the air parcel under consideration, including whether they are gases, liquids, solids, adsorbed on solids, particle size, etc. Furthermore, we need this information, insofar as possible, at the site of impact on the biological target--that is, at the point where the pollutants are inhaled.

From there on into the nasal passages or down into the lungs the question of elucidating the precise nature of the pollutant "dose" becomes a most interesting but enormously complex, multidisciplinary field of study, encompassing biochemistry, biology, medicine and indeed the physics and engineering of the transport of the pollutants in the tracheobronchial tract.

There is another problem faced by the atmospheric chemist when he attempts to elucidate the nature of the pollutant(s) "dose" at its site of entry to the biological target. Basically, the actual spectrum of pollutants experienced by man or animals, may not necessarily be the same as the "dose" that we determine using current sampling and analytical techniques. Thus, in considering existing dose-response curves for the impact of organic particulates on man or animals, we have to remember that, operationally, in the past to collect samples of ambient particulates one pulled the polluted air across the filter paper for days, and in some cases as long as a week. Having collected the sample of ambient particulates, one then analyzed it chemically and reported the chemical composition of the organic fraction. But today we should be fully aware of the fact that compounds collected on the filter and analyzed are not necessarily the sum as those that impact the biological target in the deep alveoli region of the lungs.

Therefore, one thrust of my "overview" this morning is to raise, and discuss, just such points as the possibility that reactions may occur on the filter paper during the sampling process for organic particulates and that the same reactions may or may not take place in the actual atmosphere. Thus, if one introduces into an animal organic extracts of particles collected on a filter from a Hi Vol sampler and subsequently finds that tumors are formed in that animal, the actual species responsible may not have been either a primary pollutant or a secondary pollutant formed in an atmospheric transformation. It (they) may have been formed on the filter while collecting the sample.

On the other hand, I hasten to add that when one looks at the reactivities of many polycyclic aromatic compounds, it seems quite possible--indeed probable--that many of these or similar reactions also occur in polluted urban atmospheres. Key questions are, where do they occur, to what extent, and what are they? Such questions must be answered if control officials and scientists alike are to avoid certain of the atmospheric "booby traps" prevalent in this field. Some of these issues will be dealt with by Dr. Van Cauwenberghe tomorrow.

In summary, the actual chemical and physical nature of the nitrogenous and polycyclic pollutants from diesel exhaust (as well as from conventional spark ignition engines) just prior to inhalation and then when they reach the specific biological target is highly speculative at this time. A great deal of effort has to be directed in the near future to elucidating their physical and chemical natures and biological effects if we are going to be able to evaluate in a responsible and reliable manner their possible health effects.

Let me give you another example of what I consider to be one of the important current problems facing us, specifically, determination of the chemical species responsible for the excess carcinogenicity of organic pollutants when administered to experimental animals. It has been known for over three decades that when one takes a high-volume sampler, collects particulates in ambient air, elutes the filter with an organic solvent(s) and then injects a solution into rodents they get various types of cancers, depending on the site of introduction of the material. The first experiment of this type was conducted in 1942; subsequently it was carried out with Los Angeles smog in 1954. In the latter study, Kotin and coworkers collected ambient particulates in photochemical smog on filters using Hi Vol samplers and introduced the extracts from the particulates into animals; many of these subsequently developed some malignant tumors.

Another, and striking, result of similar studies conducted during the past 15 years in several laboratories is that the degree of tumorogenicity and carcinogenicity induced in such animals was significantly greater than one could account for by the amounts of benzo(a)pyrene (BaP) and other known carcinogenic polycyclic aromatic hydrocarbons (PAH) that were measured in the ambient samples. In other words, there was an excess carcinogenicity, and this excess carcinogenicity was not simply 5 or 10 percent above the calculated on the basis of the known carcinogens determined to be present in the sample administered to the animals--it was significantly more. Thus, a fundamental question is, which are the species that are responsible for this excess carcinogenicity?

With regard to this issue, a recent study came out of Germany a year or two ago, involving exhaust from a conventional spark ignition engine in "perhaps the most popular German car." This study reported that automobile exhaust condensate introduced intertracheally produced a carcinogenic response in Syrian golden hamster lungs. Thus, as the authors [U. Mohr, H. Reznik-Schuller, G. Reznik, G. Grimmer and J. Misfeld, Zbl. Bakt. Hyg., I. Abt. Orig. B 163, 425 (1976)] state: "Both groups exhibited 100 percent rate of multiple pulmonary tumors. Considering the relatively low total dose of BaP contained in the condensate, this pronounced neoplastic response cannot be explained alone by the effects of this well-known carcinogenic hydrocarbon. This is especially so since an experiment in the same hamster strain showed that weekly intertracheal instillation of .63 milligrams per animal of BaP resulted in the development of only 50 percent of pulmonary tumors, whereas when they received the auto exhaust condensate they had 100 percent incidence of tumorogenicity. This was after an average survival time of 18 weeks."

The bottom line of this study is the comment: "However, upon contemplation of the large numbers of substances contained in automobile exhaust condensate, the question arises as to which of these compounds is responsible for the marked carcinogenic effect upon the hamster lungs."

So, the nature of such unknown pollutants, whether in exhausts from diesels or gasoline engines or in ambient air, is one of the key areas that must be explored if we are going to come up with strategies that will both protect public health and be cost effective.

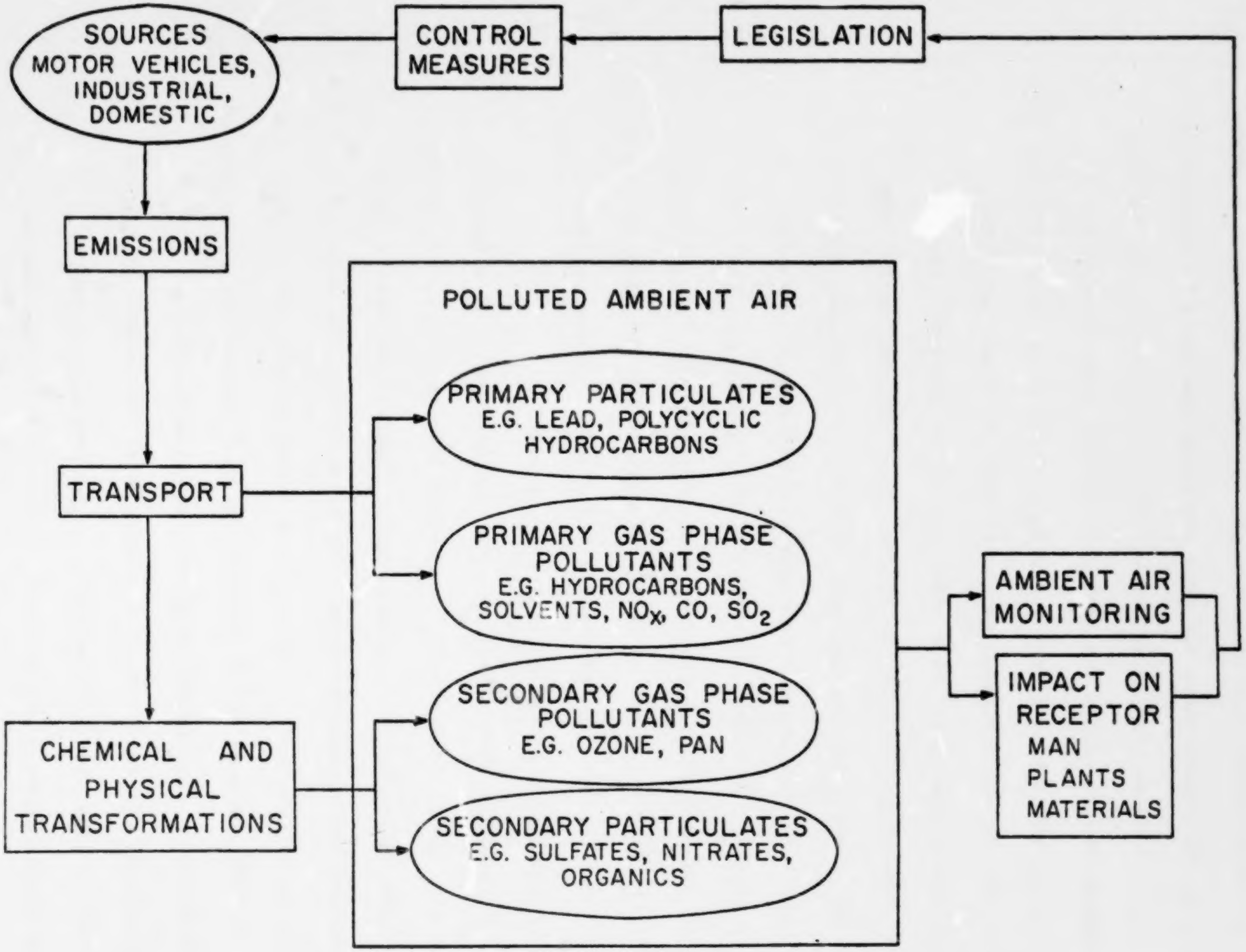
Now, in more of an overview sense, let me give you a quick look at what we feel constitutes the framework for this Conference--the air pollution system. In this, one starts with emissions, goes through transport and transformations, and then considers monitoring and impact on the receptor. I have already covered some aspects of the need to better define chemically, physically and biologically the monitoring techniques and the impact on the receptor of the components of diesel exhaust.

Slide 2 is a diagram of the System. I want to stress that in considering the possible impact of diesel exhaust we must consider all elements of this system. Thus, if we base our arguments or control strategies on only one element of this air pollution system (e.g., emissions or monitoring, etc.) and ignore its interaction with other elements, serious problems could result.

I now want to raise several issues dealing with certain elements of the system. Consider monitoring of diesel particulates.

Let us ask ourselves, how in the past have we measured, and how in the future we should measure, polycyclic aromatic hydrocarbons in diesel exhaust or in ambient organic particulates? We feel strongly that it is not sufficient (and in fact may be seriously misleading) to, for example, pass diesel exhaust through a catalyst and then evaluate its effectiveness by simply measuring the absorption or emission spectra of specific polycyclic aromatic hydrocarbons before and after treatment of the sample with the catalyst.

Thus, for example, if after catalyst treatment one sees a major decrease in the intensity of the fluorescence from BaP, it is not enough to say, "We removed most of the BaP--that solves the possible carcinogen problem." Actually, one may have in fact destroyed the benzo(a)pyrene as such--but on the catalyst formed another compound(s). This may also be



SOURCES
MOTOR VEHICLES, INDUSTRIAL, DOMESTIC

CONTROL MEASURES

LEGISLATION

EMISSIONS

TRANSPORT

CHEMICAL AND PHYSICAL TRANSFORMATIONS

POLLUTED AMBIENT AIR

PRIMARY PARTICULATES
E.G. LEAD, POLYCYCLIC HYDROCARBONS

PRIMARY GAS PHASE POLLUTANTS
E.G. HYDROCARBONS, SOLVENTS, NO_X, CO, SO_2

SECONDARY GAS PHASE POLLUTANTS
E.G. OZONE, PAN

SECONDARY PARTICULATES
E.G. SULFATES, NITRATES, ORGANICS

AMBIENT AIR MONITORING

IMPACT ON RECEPTOR
MAN
PLANTS
MATERIALS

SIMPLIFIED AIR POLLUTION "SYSTEM"

Slide 2

mutagenic or carcinogenic, but since it does not emit fluorescence or phosphorescence in the region where BaP does its formation could be overlooked.

In light of these considerations we clearly have to be very careful when we examine the presently available literature, draw conclusions as to dose-response effects of diesel pollutants and then we design new research programs to fill in our knowledge gaps. We must first ask ourselves, what really constitutes proof of a model for air pollutants. How does one "prove" something? How did one "prove" it in the past work? How should one do it now? The fact is that in order to completely characterize a chemical model for pollutant transformations one must measure not only the rate of loss of reactants, but also identify and measure the rates of formation of the products. Furthermore, one must do this for the minor, but potentially very important products, as well as for the major products. Indeed, if possible, one also identifies and measures concentrations of the reactive intermediates as the reaction progresses.

One must also do such things as conduct measurements as a function of temperature. Thus, for example, in the San Joaquin Valley, the center of California's agriculture and a vast region experiencing severe photochemical smog, temperatures can range from 50 to 60°F in the morning to 100°F in the afternoon, and concurrently one experiences a severe smog problem. Clearly one must obtain temperature coefficients for photochemical smog and incorporate them in existing computer kinetic models.

Unfortunately, I don't recall a single model for oxidant formation in photochemical smog that has realistic, experimentally validated temperature coefficients built into it. There are estimates derived theoretically for certain specific reactions, but nobody has tested the entire mechanism over a 30 to 40°F range. It is essential that we go back and look at these things very carefully before we place too great a degree of confidence in existing kinetic computer models.

Now let me go on to transport phenomena. These are illustrated in Slide 3 which shows that when considering "impact of smog on man" one has to consider far more than just the local effects of primary emissions from cars (with either conventional or diesel engines) or effluents from coal-fired powerplants. We have to realize that transport can carry polluted air masses not just one mile or 10 miles but frequently hundreds of miles--indeed over entire regions of the United States. For example, in a classic experiment, fluorescent particles (which acted as tracers) were introduced into a powerplant plume in Long Beach, California, early one morning (see Slide 3) and tracked across California's South Coast Air Basin. In one 24-hour period they were found to travel from Long Beach through Los Angeles and Riverside counties and even down into San Diego County. During this transport time--covering minutes, hours and days--a multitude of chemical and physical transformations can, and probably do, take place.

Next, let me show you a photograph of the atmospheres we must deal with. This is a picture of smog over San Jose, California, September, 1971--it is not Los Angeles or Pasadena. You can see that what one emits, whether it is diesel fumes or exhaust from my car or yours, the primary pollutants are going into a very complex atmospheric mixture. Obviously, we have to think heterogeneous when we consider introducing diesel exhaust into our urban, suburban and rural atmospheres.

Another question relevant to this conference is, how does one identify and measure non-criteria as well as criteria pollutants in such complex, heterogeneous systems. In fact, as we implied above, one has to use quite

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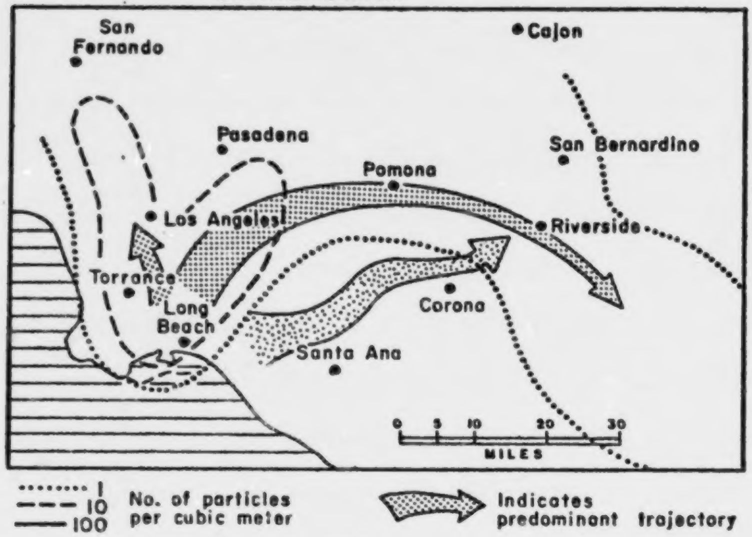
SMOKE STACK



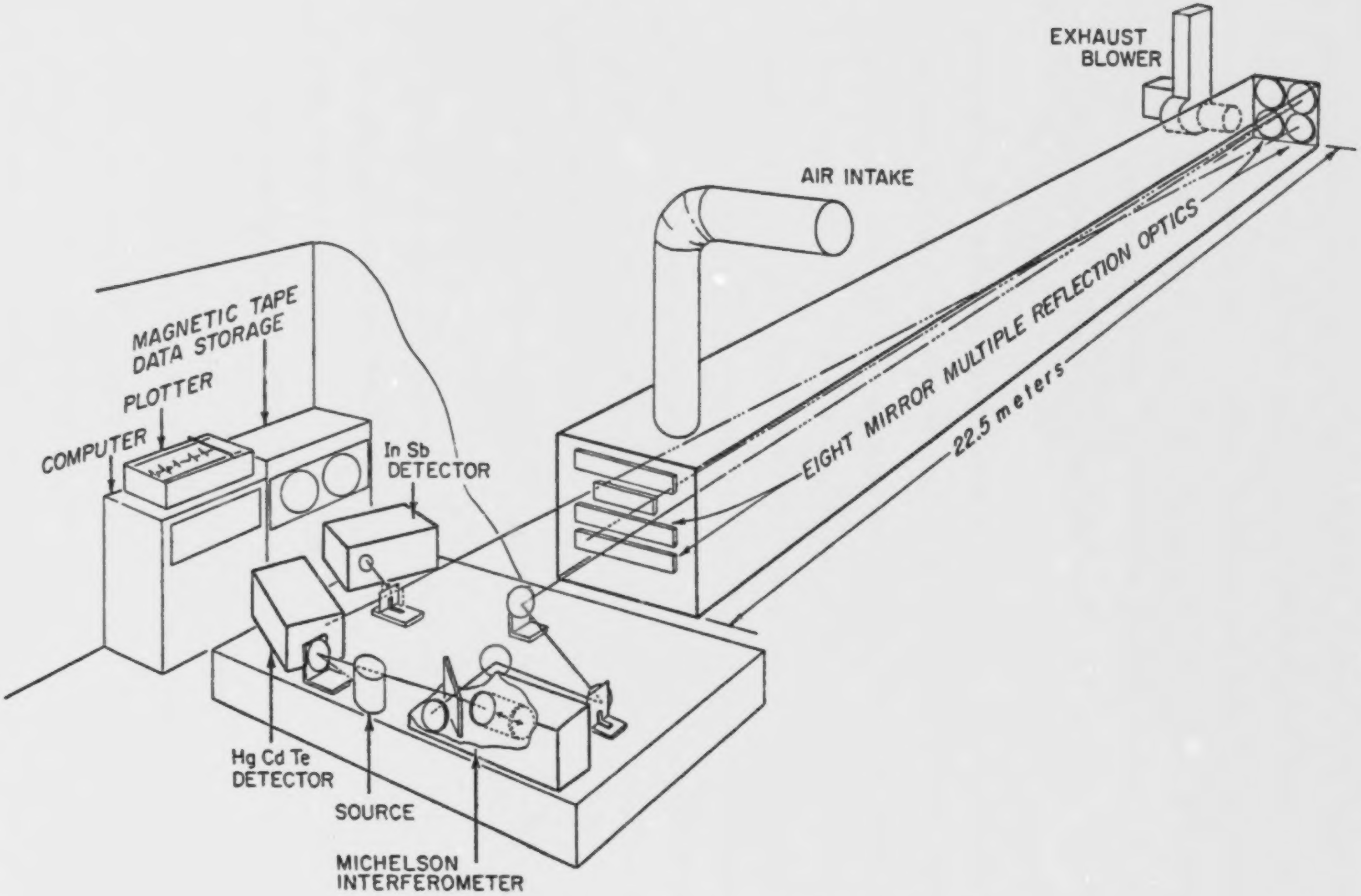
METRONICS ASSOCIATES, INC, 1974

sophisticated techniques. For example, you will recall from Slide 1 that the Clean Air Act now requires the Administrator of the EPA to evaluate the role of nitric acid as a pollutant. Actually, no one has ever systematically identified and measured nitric acid in the air by any unequivocal physical method. There has been some work done using wet chemistry techniques, but these data are not generally considered definitive.

One way to make the required physical measurements is by a technique that we at the University of California Statewide Air Pollution Research Center (SAPRC) have employed using a facility provided by Dr. Phil Hanst of the EPA. It is a kilometer optical pathlength cell mated to an FT-IR spectrometer, and is shown in Slide 4. With it we take an infrared beam from the interferometer, and reflect it back and forth on the mirrors in an eight-mirror optical system until the beam travels about one kilometer. Then we pull ambient air through the cell and measure the attenuation due to the pollutants present using a fast Fourier transform infrared spectrometer (FT-IR). In this way one can get confirmed spectroscopic proof of trace pollutants present, and measure their absolute concentrations.

Thus, one can get confirmation and quantitative data for species like nitric acid in ambient air. But, such techniques are neither simple nor inexpensive. Yet, we must at least have a limited amount of such information if we are to experimentally validate models of how diesel exhaust may interact with co-pollutants in ambient air.

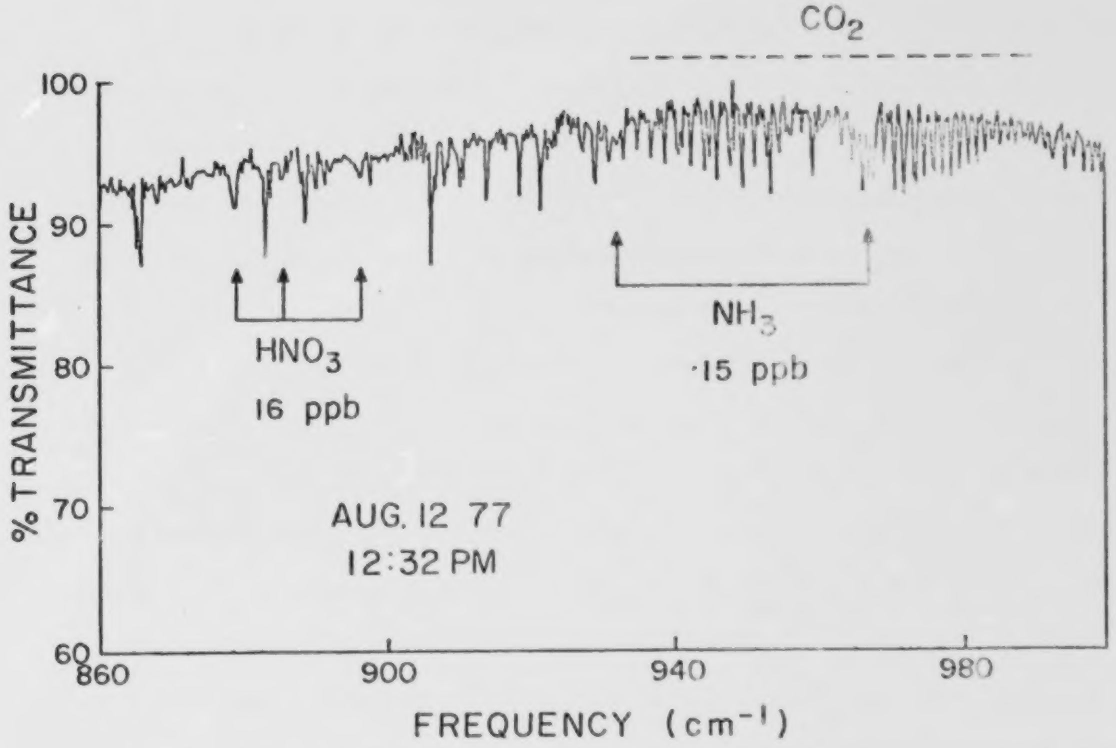
Slide 5 shows some measurements made with our long path FT-IR spectrometer in ambient smog on August 12, 1977. We see nitric acid was identified from its characteristic infrared bands and determined to be present at a concentration of 16 parts per billion (ppb). Furthermore, in the same air parcel we identify ammonia at 15 ppb.



KILOMETER PATHLENGTH MULTIPLE REFLECTION CELL
AND FT-IR SPECTROMETER

Slide 4

RIVERSIDE AMBIENT AIR



AUG. 12 77
12:32 PM

Resolution : 0.5 cm^{-1}
Pathlength : 900 meters

Detector : HgCdTe

Tuazon, Winer, Graham and Pitts (1977)

Slide 5

Isn't it interesting that one finds both gaseous ammonia and nitric acid present in the same air parcel. Going back to freshman chemistry one can ask how can we have an acid and a base coexisting? Well, ammonium nitrate does have a vapor pressure and may be in equilibrium with $NH_3(g)$ and $HNO_3(g)$--but who knows the quantitative details. Clearly, there is a significant amount of old-fashioned thermodynamics involved in understanding this system. We must look at the relationships between gaseous ammonia and nitric acid and the ammonium nitrate in solution in that droplet to get genuine understanding of the factors involved in assessing the impact of NO_x emission control strategies on nitrate particles--or in fact on gaseous nitric acid concentrations.

Having discussed an example dealing with nitrogenous species, let us examine another type of transformation--reactions of particulate polycyclic aromatic hydrocarbons in real or simulated atmospheres. First off, one of the problems that arises when one tries to understand the atmospheric reactions of PAH is certain misinformation in the literature. For example, consider this statement taken from the Annual Reviews of Physical Chemistry for 1971 referring to PAH. The authors state: "They are chemically inert and thus are removed from the air only by rain or the slow sedimentation of the particle." (Berry, R. S. and Lehman, P. A. 1971 Ann. Rev. Phys. Chem. 22, 47-84) Subsequently, an article came out in 1976 in the definitive series Chemical Mutagens and contained exactly the same statement (L. Fishbein, 1976. The quote in text is from p. 232. Hollaender, A. (ed.) Chemical Mutagens, vol. 4 (219-319) New York: Plenum Press). So, in 1976 in a Review of Chemical Mutagens one reads something which seems totally incorrect, since in fact many polycyclic aromatics such as benzo(a)pyrene, certainly have been shown to be reactive in laboratory studies.

For a number of reasons, a year ago it occurred to us to find out how PAH actually would react in simulated and real atmospheres. Dr. Van Cauwenberghe will talk about this subject in more detail tomorrow. This morning I want to give you just one example of current work in our laboratory that shows that the statement quoted above on the "non-reactivity of PAH" in polluted air is totally incorrect.

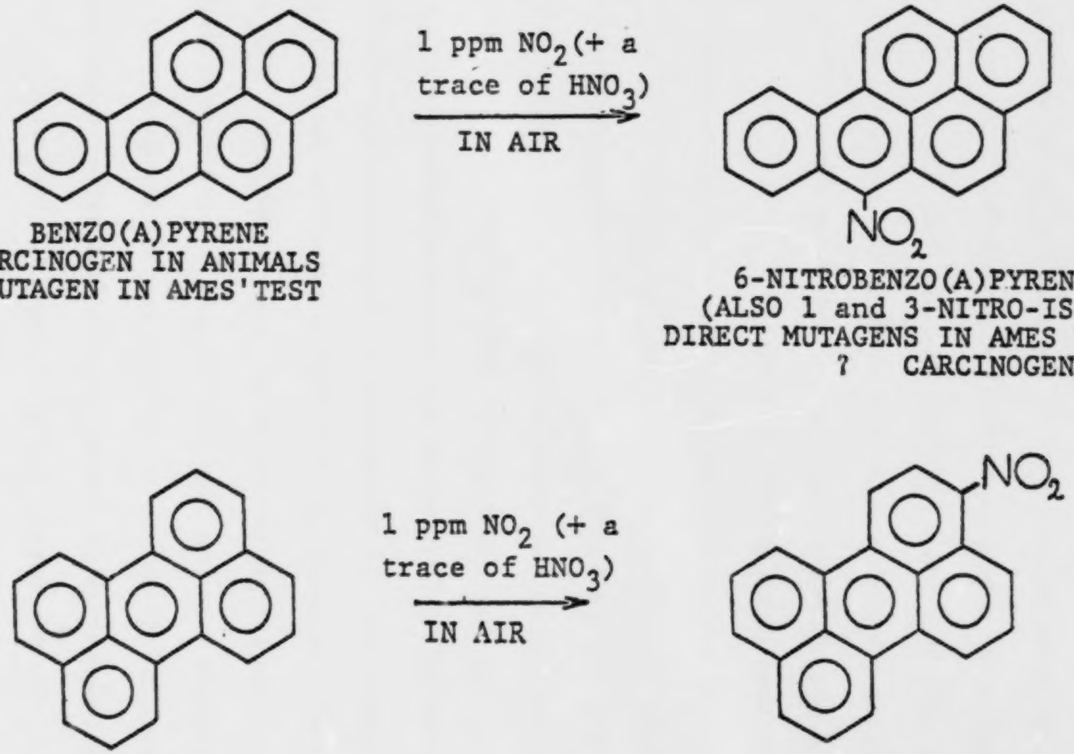
In these experiments, we started with benzo(a)pyrene, coated it on a Gelman glass fiber filter of the type typically used for high-volume sampling of ambient air and then passed NO_2 in air through it. We did not use pure NO_2, not 20 percent NO_2, but only one part per million of NO_2 in air and associated with it a small amount of nitric acid (less than ~3 ppb). Such NO_2 concentrations are not far above ambient levels (and considerably less than found in certain mines).

We passed the 1 ppm NO_2 (plus the trace of HNO_3) over the benzo(a)-pyrene for eight hours and found significant yields of 6-nitrobenzpyrene (~30%) and the 1 and 3 isomers of nitrobenzo(a)pyrene (~20% yield of the mixture of the two isomers). The reaction is shown in Slide 6.

The next slide (number 7) illustrates the kind of chemical as well as biological information one can learn from bacterial bioassays such as the Ames test. I should note at the outset, however, that we are chemists and are not using the Ames test to determine whether or not compounds, e.g., the nitrobenzo(a)pyrenes, are carcinogenic. Our interest at UC Riverside is to use this test to give us some interesting and useful chemical information on the species that may be responsible for the excess carcinogenicity of organic particulates we discussed earlier.

Benzo(a)pyrene is a promutagen (or activatable mutagen)--that is, it has to have microsomal activation by a liver homogenate system before it

REACTIONS OF A PARTICULATE CARCINOGENIC AND A PARTICULATE NON-CARCINOGENIC POLYCYCLIC AROMATIC HYDROCARBON WITH NITROGEN DIOXIDE CONTAINING A TRACE OF NITRIC ACID IN A SIMULATED ATMOSPHERE



BENZO(A)PYRENE
CARCINOGEN IN ANIMALS
PROMUTAGEN IN AMES'TEST

1 ppm NO_2(+ a trace of HNO_3) → IN AIR

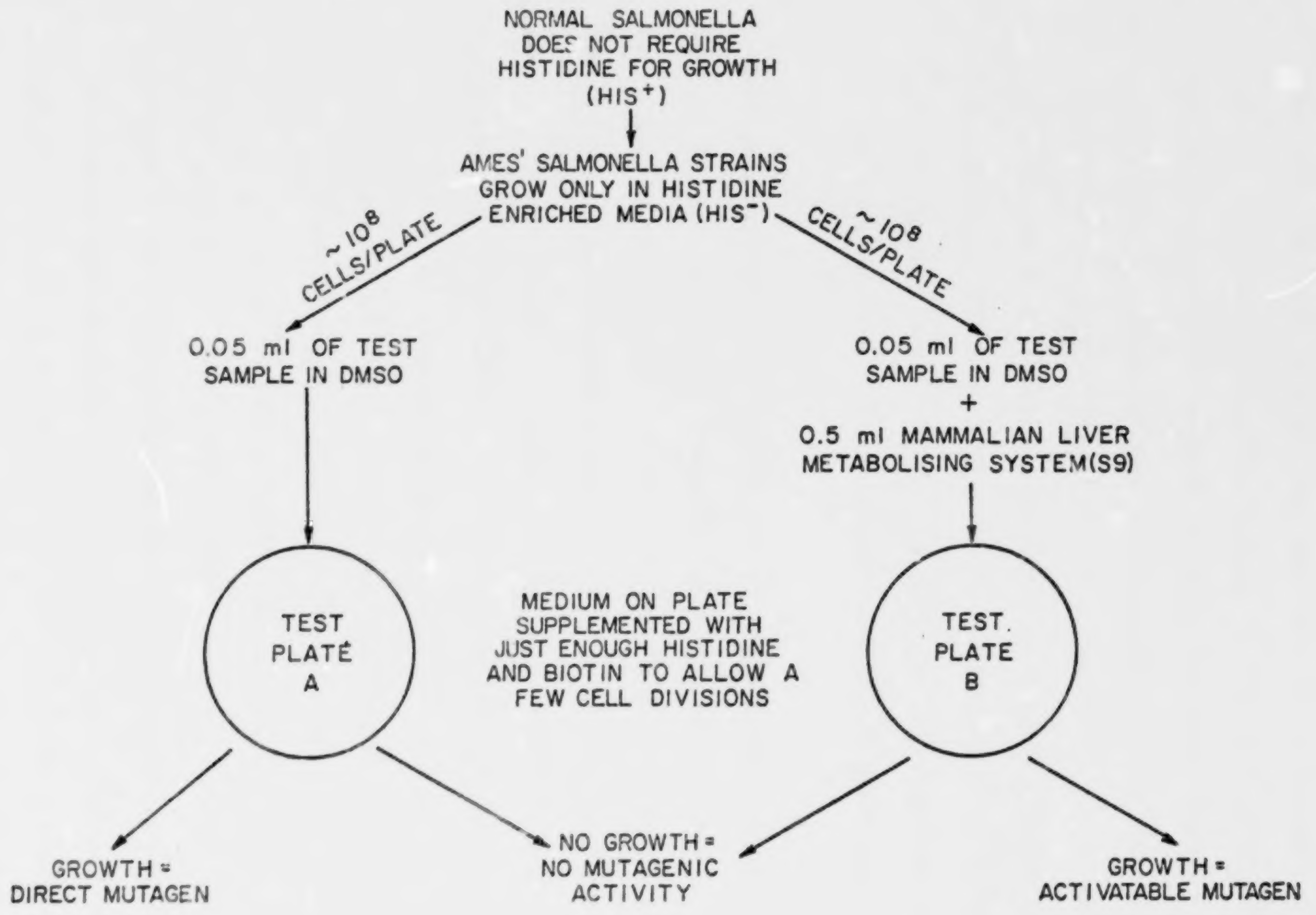
6-NITROBENZO(A)PYRENE
(ALSO 1 and 3-NITRO-ISOMERS)
DIRECT MUTAGENS IN AMES TEST
? CARCINOGEN

PERYLENE
NON-CARCINOGEN
NON-MUTAGEN IN AMES' TEST

1 ppm NO_2 (+ a trace of HNO_3) → IN AIR

3-NITROPERYLENE
DIRECT MUTAGEN IN AMES TEST
? CARCINOGEN

AMES TEST FOR MUTAGENIC ACTIVITY



NORMAL SALMONELLA
DOES NOT REQUIRE
HISTIDINE FOR GROWTH
(HIS^+)

AMES' SALMONELLA STRAINS
GROW ONLY IN HISTIDINE
ENRICHED MEDIA (HIS^-)

~10^8 CELLS/PLATE

~10^8 CELLS/PLATE

0.05 ml OF TEST
SAMPLE IN DMSO

0.05 ml OF TEST
SAMPLE IN DMSO
+
0.5 ml MAMMALIAN LIVER
METABOLISING SYSTEM(S9)

TEST
PLATE
A

MEDIUM ON PLATE
SUPPLEMENTED WITH
JUST ENOUGH HISTIDINE
AND BIOTIN TO ALLOW A
FEW CELL DIVISIONS

TEST.
PLATE
B

GROWTH =
DIRECT MUTAGEN

NO GROWTH =
NO MUTAGENIC
ACTIVITY

GROWTH =
ACTIVATABLE MUTAGEN

Slide 7

will cause a response in the Ames test (see Slide 7, Plate B). In this regard it is interesting that we recently have shown that every sample of organic particulates we collected in urban or suburban air in Southern California contained direct chemical mutagens (J. N. Pitts, Jr., D. Grosjean, T. M. Mischke, V. F. Simmon and D. Poole, Toxicol. Lett., 1, 65 (1977). Furthermore, we also showed that the mutagenic activity in the Ames test was confined to particles below 1.2 microns diameter, indeed predominately in the size fraction below .65 microns. This might be expected because this is the size range where combustion generated PAH such as BaP are generally found.

Since benzo(a)pyrene could not cause the direct mutagenic response, we concluded there must be some other compounds that do not require activation to show a response present in our samples. The question is, what are these species? We asked ourselves, could benzo(a)pyrene (and other PAH) be activated by other co-pollutants (molecules, atoms or free radicals) present in photochemical smog and be transformed from a promutagen requiring microsomal activation to a compound that does not require microsomal activation? Interestingly, our bioassay team, headed by Professor Belser of UCR, tested the nitrobenzo(a)pyrenes (shown in Slide 6) and found that the one, three and six isomers are all direct mutagens.

The next question was, given that we could convert a PAH that is a known carcinogen in animals and a promutagen in the Ames test to a direct mutagen, could we take a non-carcinogenic, non-mutagenic PAH known to be present in ambient particulates and auto exhaust and by similar treatment in a simulated polluted atmosphere convert it to a compound that is a direct mutagen?

We took perylene, a non-carcinogenic, non-mutagenic (in the Ames test using reverse mutations) isomer of BaP and coated a similar filter with it. It was exposed for eight hours in a Hi-Vol sampler to 1 ppm of NO_2 (containing traces of HNO_3). We found that the perylene went very readily to 3-nitroperylene and in good yields. Thus, in fact we transformed a non-carcinogen, non-mutagen to a direct mutagen--which becomes an even stronger mutagen upon microsomal activation.

Basically, what these initial experiments tell us is that one cannot just look at diesel emissions, for example, and say, "That is perylene, a non-carcinogen--we don't have to worry about it."

By the way, we also performed the same experiment using pyrene, a non-carcinogenic, non-mutagenic PAH with four aromatic rings. We found it reacted in a similar manner to form nitropyrene, although to a much lesser extent than BaP or perylene. This is exactly what one might predict from considerations based on theoretical organic chemistry. Thus a quadricyclic molecule (pyrene) should be less reactive in this nitration reaction than the two pentacyclic compounds BaP and perylene.

One note of caution, however. We must recognize that if one deposits benzo(a)pyrene on charcoal particles, for example, instead of on a glass fiber filter, one may get a different reactivity sequence, indeed different reactions. The surface upon which the nitration reaction takes place, for example, may make a significant difference in the products and yields.

In conclusion then, we have talked briefly about emissions, chemical transformations, collecting and monitoring, and impact on biolgocial receptors. Clearly when studying the impact of increased emissions of diesel exhaust on ambient air quality each of these elements must be viewed not only in their own right, but also in the context of their interrelations in a complex air pollution system.

Finally, we wish to acknowledge support of the research presented here by the National Science Foundation-RANN (Dr. Richard Carrigan, grant monitor), the Environmental Protection Agency (Dr. Philip Hanst), the

California Air Resources Board (Drs. John Holmes and Jack Suder) and the University of California. However, the views expressed here are our own and not necessarily those of these agencies or of the University of California.

Thank you.

PROF. JOHNSON: Thank you very much, Jim, for a very fine overview on some of the problems that we face in terms of going into the laboratory and trying to make measurements. It is a difficult problem, and what I would like to do now is to give the second paper.

I felt it would be useful to go through the state-of-the-art of some of our measurement work very briefly so to set the stage. I am sure that there will be other people that will maybe touch on some of these same items.

The topic of my talk is the "Characterization of Diesel Particulate Emissions." We have been doing wokk since about June, 1974, on diesel particulate emissions. Because of the availability of diesel engines and because of the larger number of diesels in the truck market, we have been looking at largely a medium duty type of diesel for our characterization work.

The work that I am about to talk about is really summarized in three SAE papers: 760131, SP430 which we gave at the last SAE meeting in February, and 780111 which was also given at the recent SAE meeting.

I hesitate a little bit after Jim. In the SP430, we have quoted the literature a lot; and I suspect maybe we have quoted some of the things that are wrong in the literature. The literature is very extensive in terms of particulate emissions in flames and also in other types of sources; and we have over 222, or around that number, of references in SP430. There are probably many more references in the literature that build on this whole field.

What I would like to do here is to lay some of the foundation of what is particulate matter from our research. I would like to talk a little bit about measurement of size distribution in the laboratory and the sulfate measurement. We have done some sulfate measurements, a little bit about the total mass characteristics of the engine; and I would like to get into talking about the techniques that are presently being used in our lab pretty widely in terms of getting at the soluble organic fraction which would probably contain lube oil and unburned fuel or oxidized fuel compounds from the combustion process. There probably are some deficiencies, and to bring these out is really the purpose of this meeting. So, what I would like to do is to go through these slides of some of our test apparatus to bring you back now to the diesel engine laboratory, a dynamometer laboratory. For light duty vehicles, what would be different about it would be that there would be a chassis dynamometer rather than an engine dynamometer. So most of the slides, just as a background, will be illustrative of a medium duty or heavy duty type of engine test where the test is done on an engine dynamometer; and so, if I could have the first slide please? #1

The vehicle going down the road, whether it be a car or a truck, the source of the particulate from an engineering viewpoint and what has ultimately got to be solved if you really want to get back to the source, is in this combustion chamber where things take place in terms of milliseconds.

The other part of the system that we recognize where you can make measurements, it is obviously not an equilibrium, but it is a place from an engineering viewpoint that you might want to examine,, it is in this undiluted exhaust. It is in high concentrations, and you can easily study the mass concentrations or the organic fraction; but it might not be what ultimately people breathe in the atmosphere.

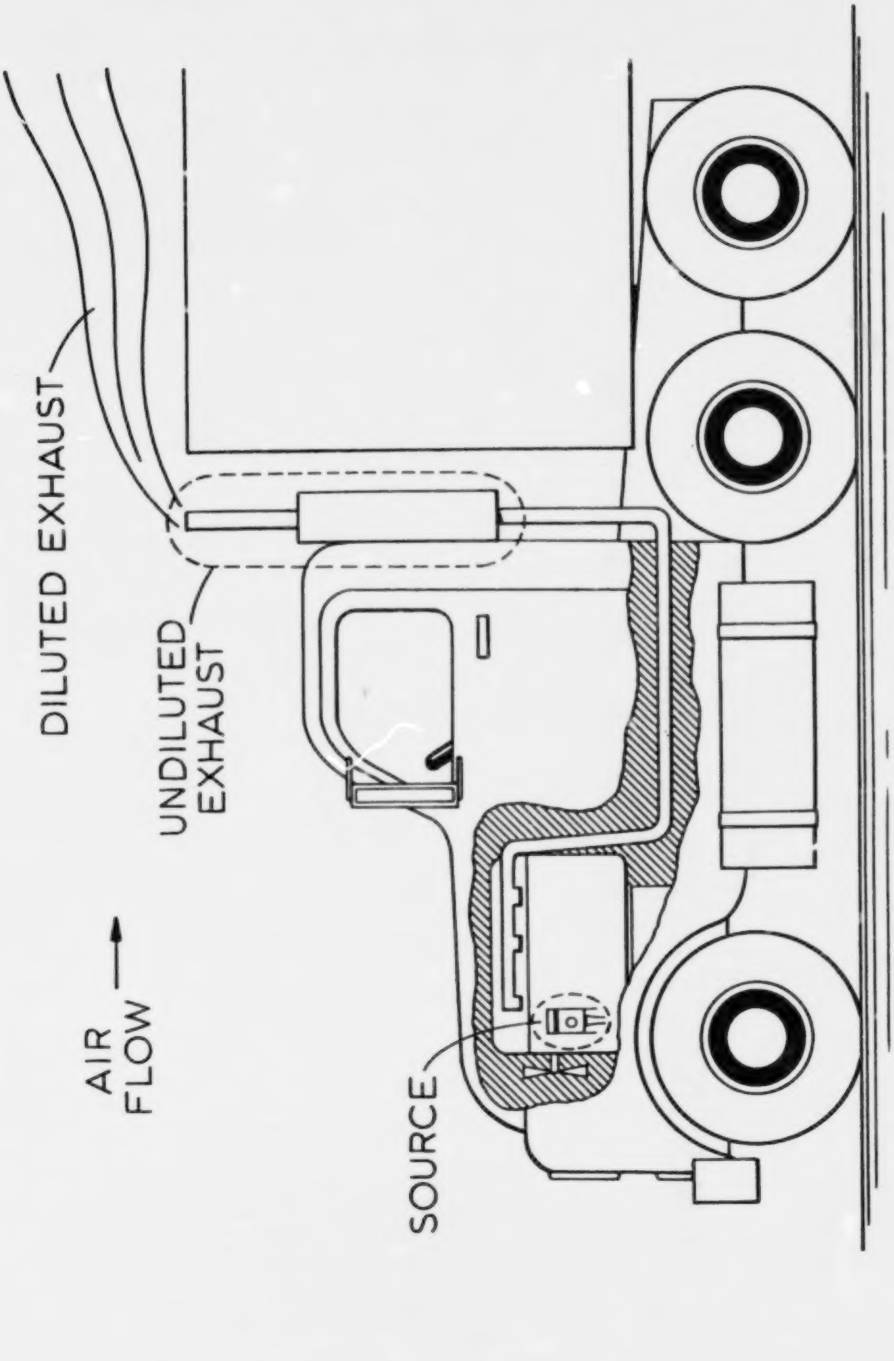
The other thing that we want to measure is the diluted exhaust, and this is where we get into dilution tunnels in the laboratory to try to start to simulate this process. Obviously, the time scale cannot be exactly like the atmosphere.

Unfortunately, the dilution ratios that we have been operating so far, from a practical engineering viewpoint, are low because you really push your engineering accuracy and the overall engineering development cycle as you go to higher dilution ratios in terms of simulating this particular process in a laboratory.

Could I have the next slide, please? #2

Basically, what we are talking about then is the particle phase, is any dispersed matter, either solid or liquid, present in

JOHNSON - 1



SLIDE 1

PARTICLE - DEFINITION

ANY DISPERSED MATTER PRESENT IN DILUTED EXHAUST GASES AT APPROXIMATELY AMBIENT CONDITIONS ________....

$$\text{AMBIENT} \left\{ \begin{array}{l} \text{TEMPERATURE} \\ \text{PRESSURE} \\ \text{AMOUNT OF DILUTION} \end{array} \right.$$

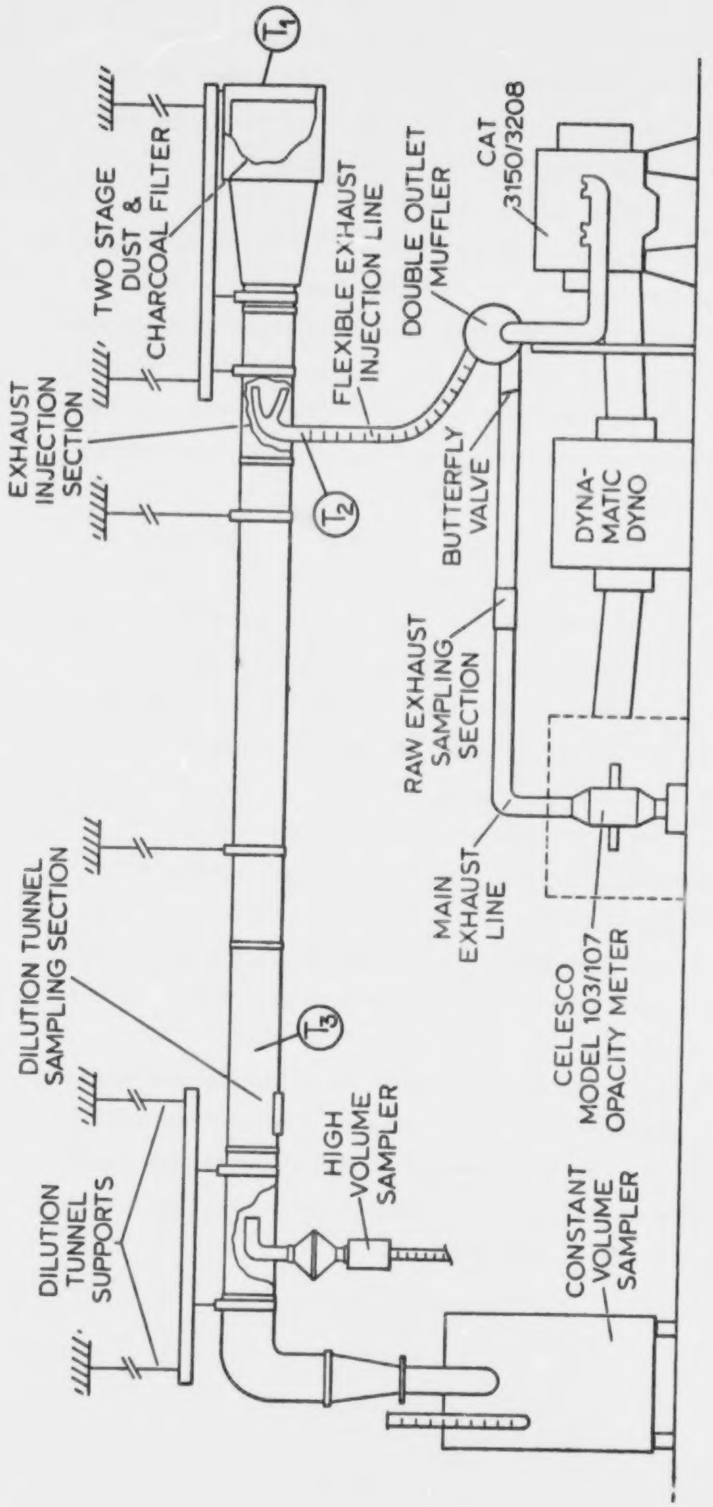
diluted exhaust at approximately ambient conditions; and it is, obviously, a function of temperature, pressure and the amount of dilution, and we have certain limitations that we deal with in the laboratory to get repeatability and to get accuracy in terms of trying to implement this fundamental definition in terms of the dose that people receive which we are trying to simulate in the laboratory and carry on our engineering developments.

Could I have the next slide, please? #3

This is our test section and our tunnel. We have an engine dynamometer with the Caterpillar 3150 engine, and we now have a 3208 engine. On the other end we have hooked up into this system a Cummins 903 engine that we can also use for particulate measurements. We split in our system only a part of the exhaust up into the tunnel here. The fresh air is brought in through the filter which is a dust filter and a charcoal filter which is the front half of the CVS system. We have a 12-inch duct here in stainless steel. Down to our test section here, we have a dilution test section,, and this is a high-volume sampler where we can collect about 1 gram or 1/2 gram of material for chemical characterization work. We have on the end of the system a constant volume sampler,and the roots blower to draw the air,and the exhaust through the system. We can set the back pressure on the engine so that we can get the amount of exhaust flow that we want to simulate the dilution ratio.

We have been working typically in the range between about 10 to 1 dilution ratiooto about 50 to 1, and this has been set largely by practical limitations. If you go to higher dilution ratios, you have extremely long times of collecting mass, at least in the stage we are at;;and so, it is very difficult.

In the splitting here, you are faced with the larger engines of having such a tremendous volume of exhaust in order to do full dilution, you would have such a tremendous dilution tunnel that most people that have worked with engines of this size have worked with fractional splitting of the exhaust.


T1
TWO STAGE DUST & CHARCOAL FILTER
EXHAUST INJECTION SECTION
FLEXIBLE EXHAUST INJECTION LINE
DOUBLE OUTLET MUFFLER
CAT 3150/3208
T2
BUTTERFLY VALVE
DYNA-MATIC DYNO
RAW EXHAUST SAMPLING SECTION
MAIN EXHAUST LINE
CELESCO MODEL 103/107 OPACITY METER
DILUTION TUNNEL SAMPLING SECTION
T3
HIGH VOLUME SAMPLER
DILUTION TUNNEL SUPPORTS
CONSTANT VOLUME SAMPLER

SLIDE 3

Most of the light duty work is done with probably lower dilution ratios, maybe in the 5 to 10 to 15, maybe up to 20 dilution ratio depending on the size of the engine with full dilution in the tunnel.

Could I have the next slide, please? #4

The type of apparatus that we are using, and I think it is pretty common because of working with masses, is to have various probes up in the test section. We have a separate fluoropore filter for our sulfate sample. We have a probe for our TSI 3030 ambient instrument for measuring particle size distribution. We have worked with an Andersen impactor in both the diluted and undiluted exhaust. We have used normal sampling gear for stationary stacks, which has a dry gas meter and a vacuum pump and an impinger section to draw the sample from the test section.

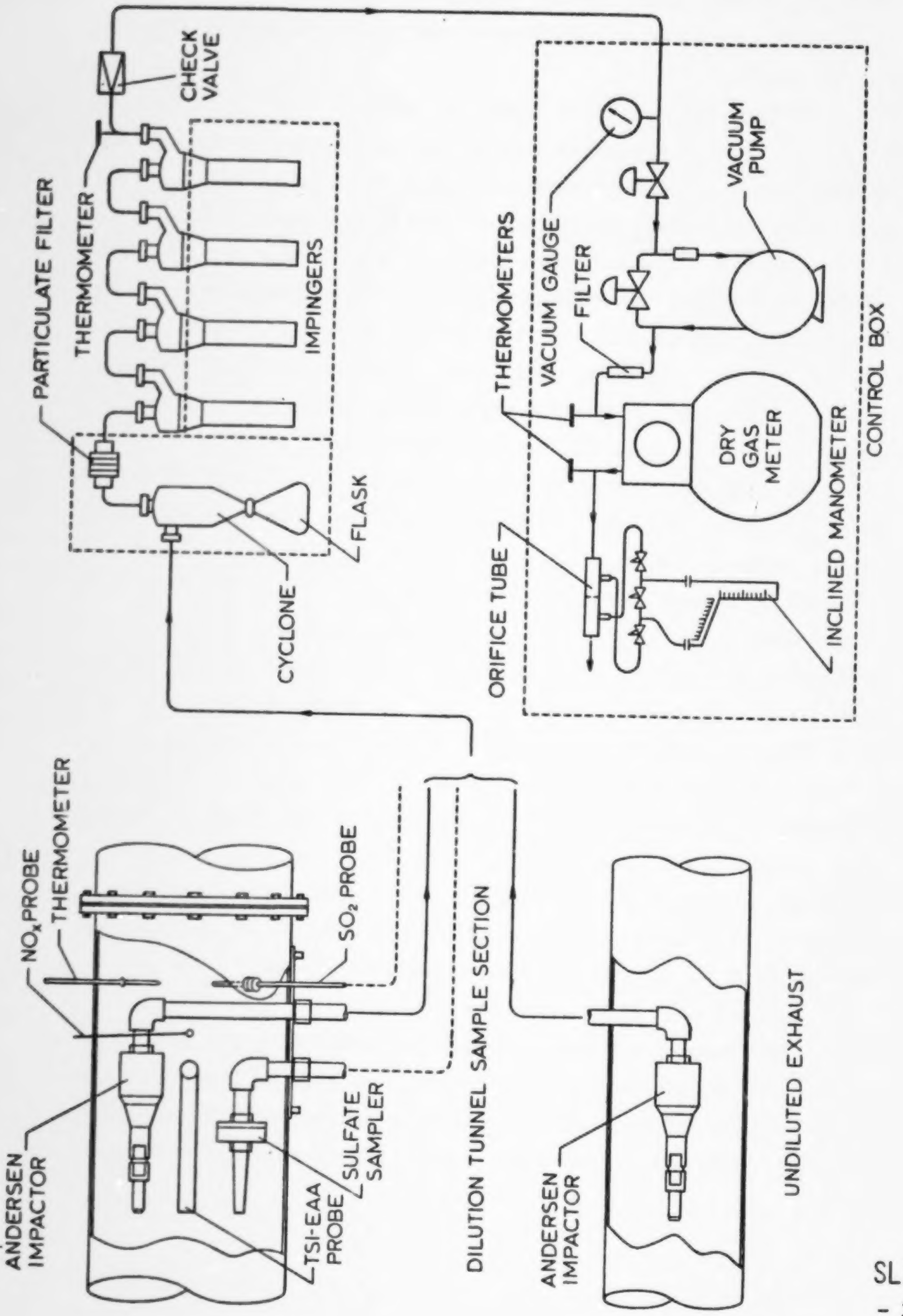
We have also worked with measuring SO_2 in the dilute exhaust using a flame photometric instrument that has been modified so that we can characterize the SO_2 level in the diluted exhaust.

Could I have the next slide, please? #5

This is one of our micrographs taken from a stage of the Andersen impactor collected on a grid and in the transmission electron microscope. This is probably the largest particle that we have found. We don't know whether this broke off from the exhaust system. When we make a collection like this, we collect for about a couple of minutes; but this is the largest particle. If we had this under a higher magnification, and I will show you some other pictures, we would see individual spheres here of about 100 angstroms in size, up to as large as this 20 micrometer agglomerate that we find on this particular micrograph.

Could I have the next slide, please? #6

This shows a different magnification showing the very chain-like structure of the solid soot particles that we find. This is in the dilute exhaust, and this is some recent work in the undiluted exhaust. These micrographs are not in the papers that I referred to.


PARTICULATE FILTER
THERMOMETER
CHECK VALVE
IMPINGERS
CYCLONE
FLASK
THERMOMETERS
VACUUM GAUGE
FILTER
VACUUM PUMP
DRY GAS METER
ORIFICE TUBE
INCLINED MANOMETER
CONTROL BOX
NO$_x$ PROBE
THERMOMETER
SO$_2$ PROBE
ANDERSEN IMPACTOR
SULFATE SAMPLER
TSI-EAA PROBE
DILUTION TUNNEL SAMPLE SECTION
ANDERSEN IMPACTOR
UNDILUTED EXHAUST

SLIDE 4

SLIDES 5, 6, 7

(PHOTOGRAPHS OF DIESEL PARTICLES ARE AVAILABLE IN SAE PAPERS 760131 AND SAE 780108 (SPECIAL PUBLICATION 430)).

It is at a dilution ratio of 34 to 1 and for a particular engine condition, just to show you the types of particles that we get.

Could I have the next slide, please? #7

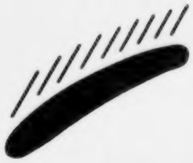
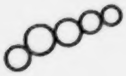
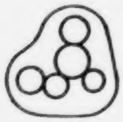
This is some additional dilute exhaust at a lighter load condition, some micrographs that we took just in the dilute exhaust. These are for three different engine conditions and three different modes, and we think that this is the hydrocarbons. We feel that there is a lot of interaction between the gaseous phase as this is diluted down, and we feel that this is indicative of the hydrocarbons--this impact area. We find a different character of the particles, although it is hard to give a descriptive character to the differences.

Could I have the next slide, please? #8

What we, then, have come up with, through all our micrographs and thinking about it and doing the chemistry, is this kind of schematic to show the types of particles that we feel are present in the exhaust in these various parts of the system.

We find in some of our micrographs, not in large numbers, a solid liquid particle. It is a long chainlike, probably very heavy high molecular weight, compound. It is in a long chain type of structure. The most typical particle is these chains that you have just seen, these aggregates which are built with building blocks of 100 to 800 angstrom spheres in diameter; and these are very similar to flame studies. You find these same particles being generated.

There would be liquid sulfate particles, probably. Liquid hydrocarbon particles could be present either from late injection process or actually going from the gas phase to the liquid phase. There will, obviously, be gassy phase heavy hydrocarbons that can interact with these solid and liquid particles; and so we feel that there is also the solid chain aggregates with high molecular weight organic compounds and/or inorganic species such as SO_2, NO_2, sulfuric acid, and sulfates adsorbed onto the surface.

	Solid/Liquid Particles
	Solid Chain Aggregates (100-800 Å sphere building blocks)
○	Liquid Sulfate Particles
○	Liquid Hydrocarbon Particles*
●	Gaseous Hydrocarbons*
	Solid Chain Aggregates with High Molecular Weight Organic Compounds* and/or Inorganic Species such as SO_2, NO_2, H_2SO_4, and Sulfates adsorbed on Surface

*Unburned Hydrocarbons, Oxygenated Hydrocarbons (Ketones, Esters, Organic Acids) and Polynuclear Aromatic Hydrocarbons

These could be hydrocarbons, oxygenated hydrocarbons, ketones, esters, organic acids, and polynuclear aromatics; and, to expand on what Jim said, we feel that the whole aspect of looking at these organic compounds is important from an engineering and from a research viewpoint in terms of characterizing the emissions coming out of diesel engines. I think a lot of the literature in the past has looked just at the polynuclear aromatic compounds and not taken this broad aspect of looking at other organic compounds that might be present.

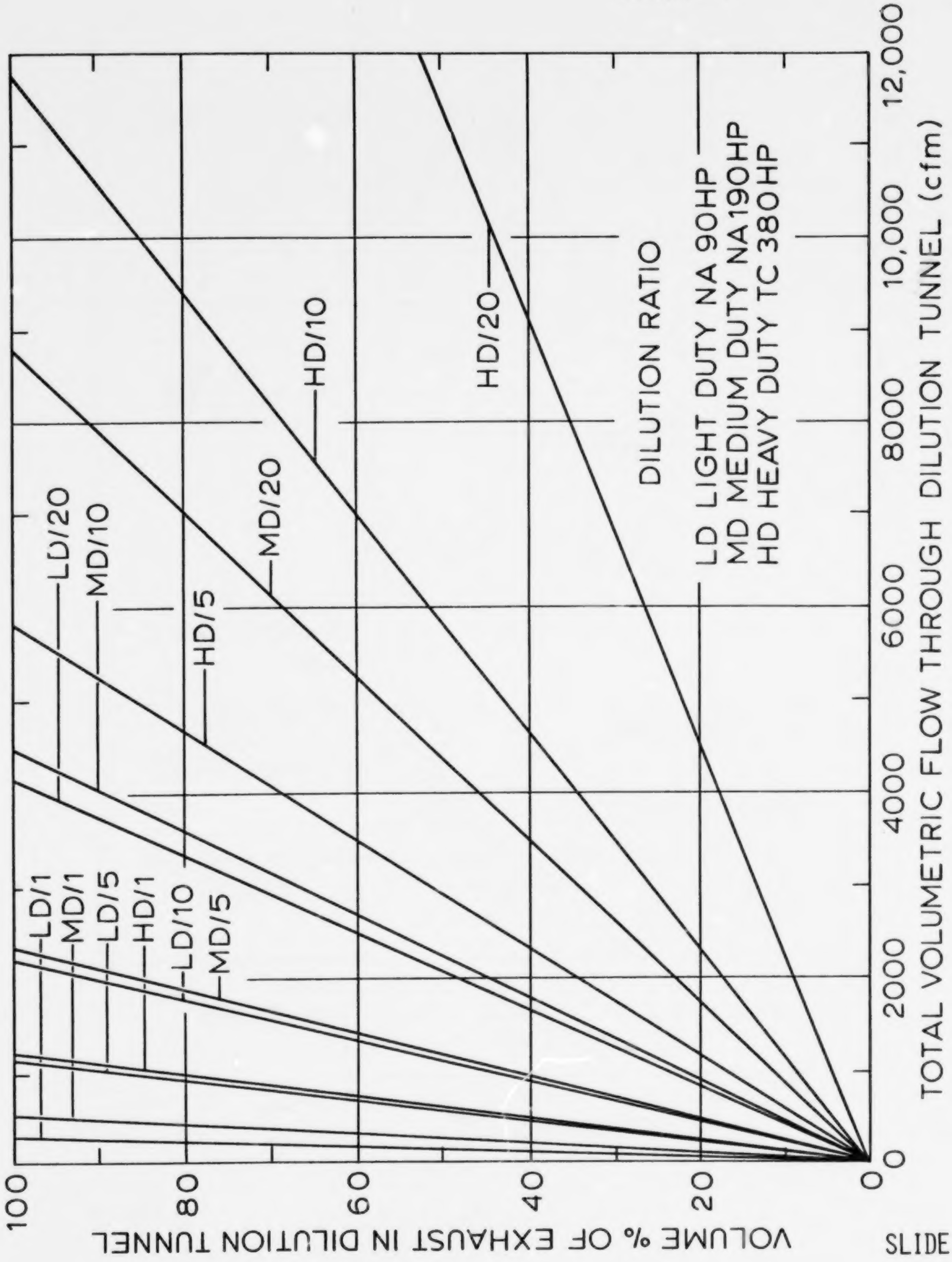
Could I have the next slide? #9

When you go to the tunnel then, I would like to address this question of dilution ratio that I raised earlier when you get to different size engines.

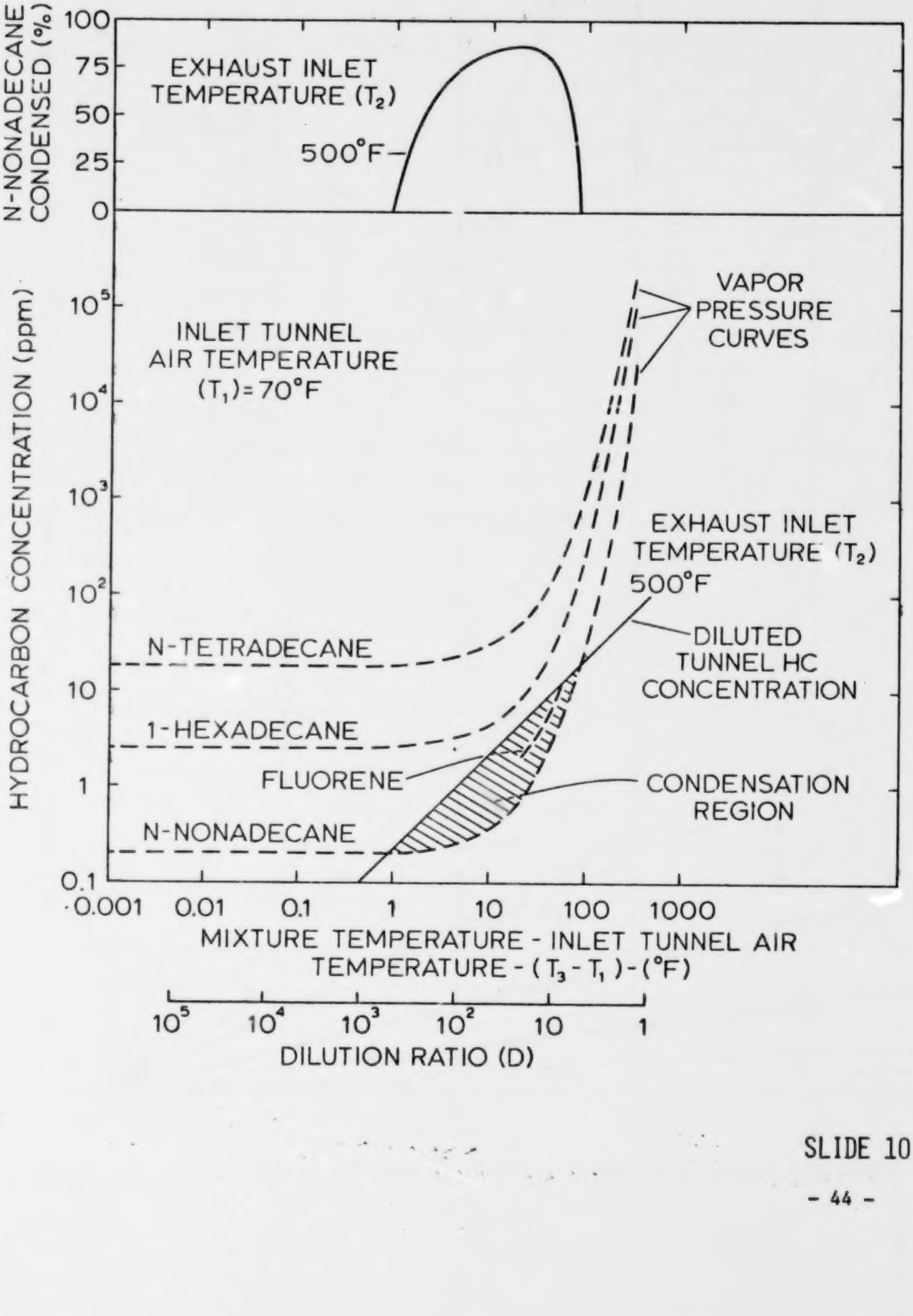
We have done a calculation with different size engines or different horsepower engines, from a heavy duty engine of 380 horsepower, to a medium duty of 190, to a light duty of 90 horsepower; and we have plotted the total volumetric flow through the dilution tunnel way out to 12,000 CFM, and what we have on here is different dilution ratios for these different size engines at full load condition, i.e., they were running at full load. This is a heavy duty engine at a 5 to 1 volumetric dilution ratio, the heavy duty at 10 to 1, and the heavy duty at 20 to 1. You can see how large this volume dilution ratio has to be in order to do full dilution and to get to higher dilution ratios, which are really what the atmosphere sees in terms of the dose; and you can see in the light duty all the way from the low dilution ratios of 5, 10, and 1 to 1, and the light duty 20 to 1, even to get 20 to 1 at full load condition you need up to 4000 CFM in this tunnel, which makes a very large facility. So, that is one of the problems, in terms of the laboratory, of actually doing this characterization.

Could I have the next slide, please? #10

We have also carried out some very elementary calculations, in terms of the traditional dew point calculations for water, just to show what happens under very equilibrium conditions without any


VOLUME % OF EXHAUST IN DILUTION TUNNEL
100
80
60
40
20
0
TOTAL VOLUMETRIC FLOW THROUGH DILUTION TUNNEL (cfm)
0
2000
4000
6000
8000
10,000
12,000
LD/1
MD/1
LD/5
HD/1
LD/10
MD/5
LD/20
MD/10
HD/5
MD/20
HD/10
HD/20
DILUTION RATIO
LD LIGHT DUTY NA 90HP
MD MEDIUM DUTY NA190HP
HD HEAVY DUTY TC 380HP

SLIDE 9


N-NONADECANE CONDENSED (%)
100
75
50
25
0
EXHAUST INLET TEMPERATURE (T_2)
500°F
HYDROCARBON CONCENTRATION (ppm)
10^5
10^4
10^3
10^2
10
1
0.1
INLET TUNNEL AIR TEMPERATURE (T_1) = 70°F
VAPOR PRESSURE CURVES
EXHAUST INLET TEMPERATURE (T_2)
500°F
DILUTED TUNNEL HC CONCENTRATION
N-TETRADECANE
1-HEXADECANE
FLUORENE
CONDENSATION REGION
N-NONADECANE
0.001
0.01
0.1
1
10
100
1000
MIXTURE TEMPERATURE - INLET TUNNEL AIR TEMPERATURE - (T_3 - T_1) - (°F)
10^5
10^4
10^3
10^2
10
1
DILUTION RATIO (D)

SLIDE 10

particles using simple Dalton law and using some calculated vapor pressures that we could find in the literature.

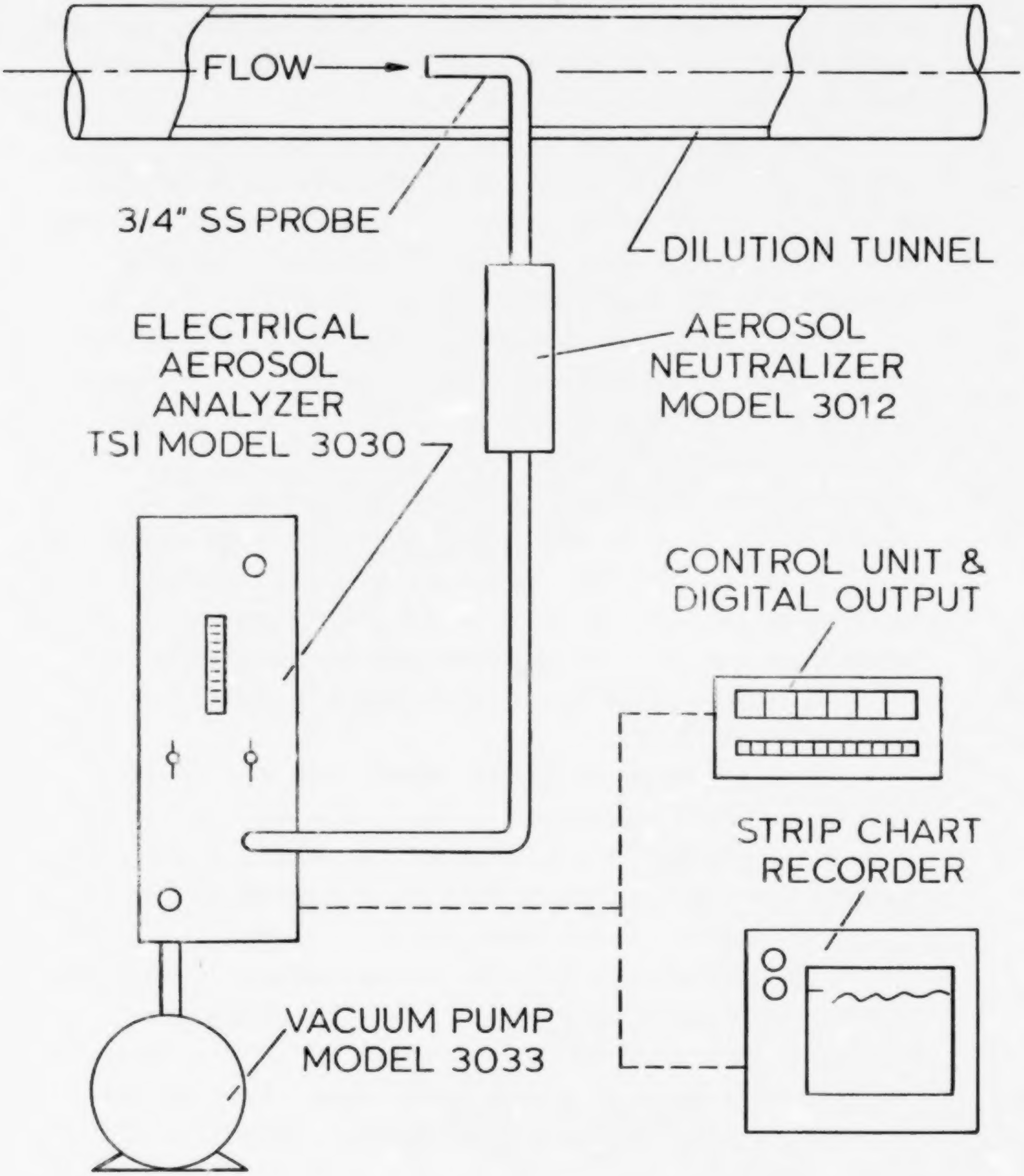
So, what we have here is the hydrocarbon concentration in parts per million. We have the mixture temperature, the inlet tunnel air temperature, and the mixture temperature minus the inlet tunnel temperature; and the calculation was done for a 70 degree inlet air temperature into the tunnel.

If we start out with 100 parts per million of one of these species and if we work through the dilution process in terms of what it does to the mixture temperature here,(this is a log scale), we would follow this curve if we make certain very simplified assumptions in the calculations. If the exhaust started out at 500 degrees F and we superimpose these vapor pressure curves, we would find, if we had an intersection, theoretically, this would be a condensation region; and if we plot the percent condensed for the N-nonadecane, we would find that it would peak around 50 to 100 to 1 in this theoretical calculation. Now, what actually happens on the filter or what happens with these chain organic compounds is another question. We are not trying to answer that question; but we just want to go through the fundamentals of diluting a gas that is in the gas phase from simple Dalton's law ideal gas considerations of what would happen in terms of this condensation phenomena.

We are not saying in this calculation that this is indeed what happens; but it points out the complexity, not only the reactions, but the physical processes and the chemical processes that take place when you go through dilution processes in a tunnel.

Could I have the next slide, please? #11

To measure particle size distribution, we have used both the impactor; and we have, more recently, used this thermo systems instrument, which is an ambient instrument. It is very sensitive. The impactor is sensitive to mass distribution. You weigh the plates or you weigh the substrates. This instrument is sensitive


FLOW
3/4" SS PROBE
DILUTION TUNNEL
ELECTRICAL
AEROSOL
ANALYZER
TSI MODEL 3030
AEROSOL
NEUTRALIZER
MODEL 3012
CONTROL UNIT &
DIGITAL OUTPUT
STRIP CHART
RECORDER
VACUUM PUMP
MODEL 3033

SLIDE 11

to number distribution; and, because we are dealing largely with the impactor, we find that 90 percent is less than 1 micrometer by aerodynamic sizing.

The density of these particles, the effective density, found in traps is around .03 or .07 grams per cubic centimeter; and you find that they are very light and fluffy aerodynamically. So, this is a very sensitive instrument. You have to dilute down, probably, to 100 to 1 because it saturates at about 1 milligram per meter cubed because it is an ambient instrument.

Could I have the next slide, please? #12

We took a number of our data from engines; and, if we plot the cumulative percent number of particles less than a given diameter going all the way from 1 micrometer, which this instrument is sensitive below that, we find on a number basis by the number of particles, not on the mass distribution, that all of it, from a practical viewpoint, occurs below 1 micrometer, and the 50 percent point is around .01 mm with this instrument.

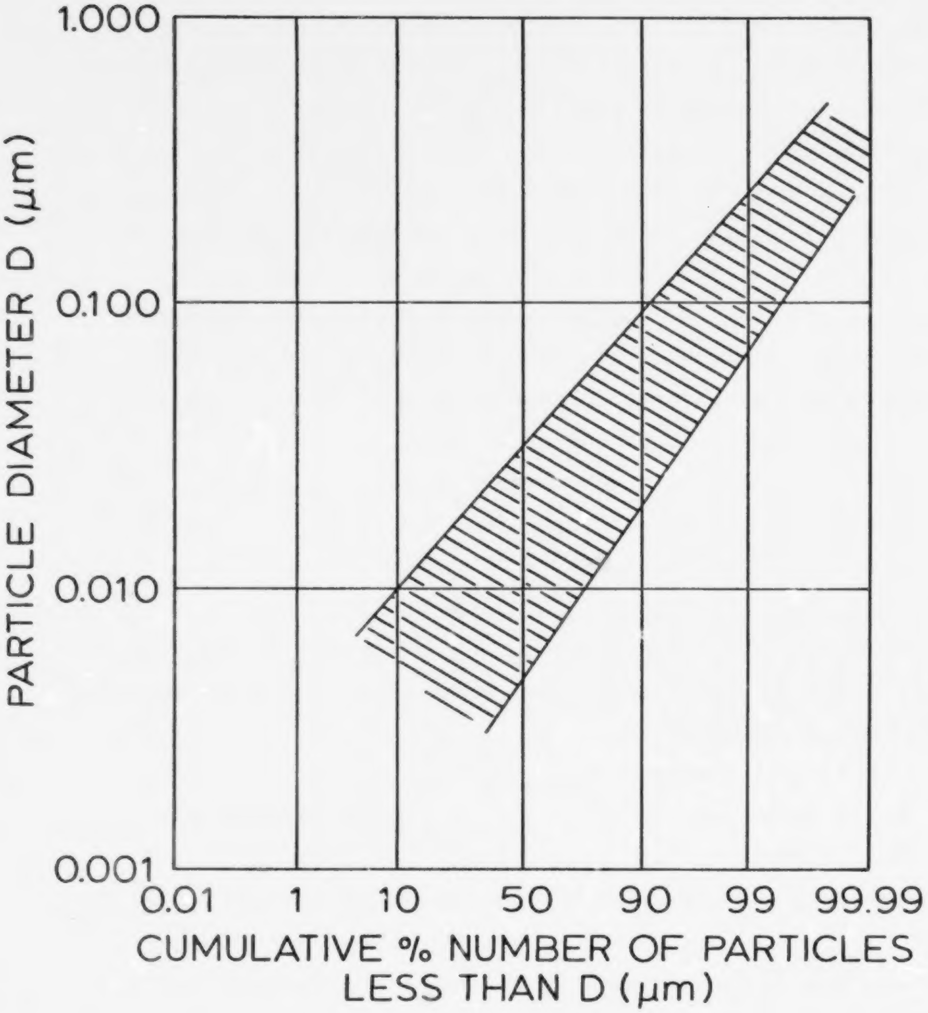
Now, what this instrument really measures with these chain agglomerates is another unanswered question. It is a very complex question with these soot particles in terms of the charge mobility; but it is a response by another instrument that is sensitive to size distribution, and it is calibrated, obviously, on spheres. So, it is hard to say what this number means; but it does mean that they are indeed respirable.

Could I have the next slide, please?

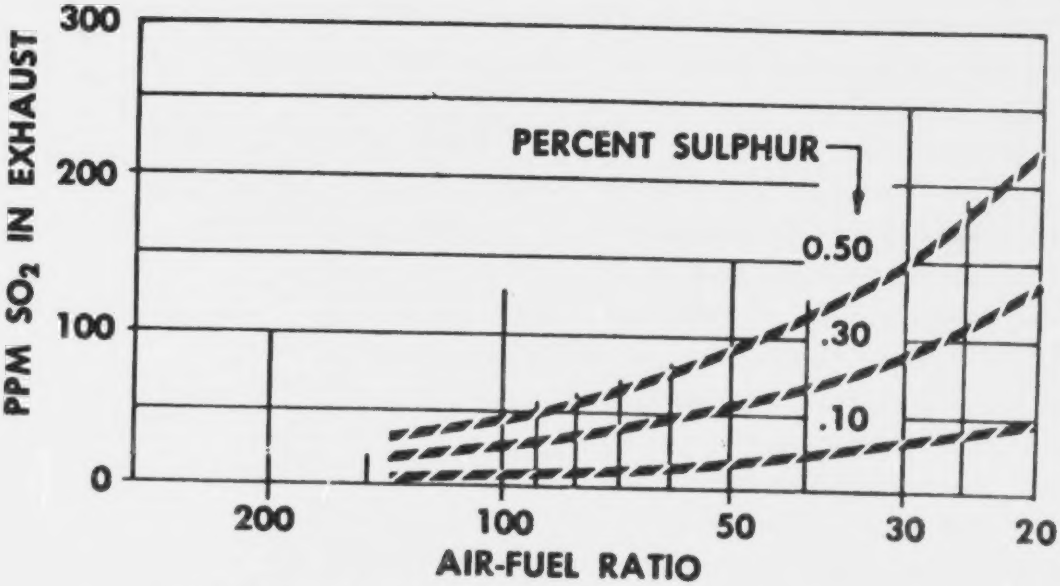
What I would like to talk about is sulfate measurement.

Could I have the next slide, please? #13

With typical sulfur levels from diesel fuel, we find that versus the air fuel ratio then with a theoretical calculation of converting all of the sulfur in the fuel to SO_2 that we find various concentrations of SO_2 versus the load on the engine with this being a full load and this being light load back at 100 to 1 that we will get various concentrations of SO_2.


1.000
0.100
0.010
0.001
PARTICLE DIAMETER D (μm)
0.01
1
10
50
90
99
99.99
CUMULATIVE % NUMBER OF PARTICLES LESS THAN D (μm)

SLIDE 12



Effect of percent sulfur in diesel fuel on sulfur dioxide emissions assuming all sulfur is converted to SO_2

SLIDE 13

This can be converted even in the dilution tunnel and in the exhaust into sulfate, and we have been working with the barium chloranylate method and modified it slightly to measure the sulfate fraction from the 3150 Caterpillar engine.

Could I have the next slide, please? #14

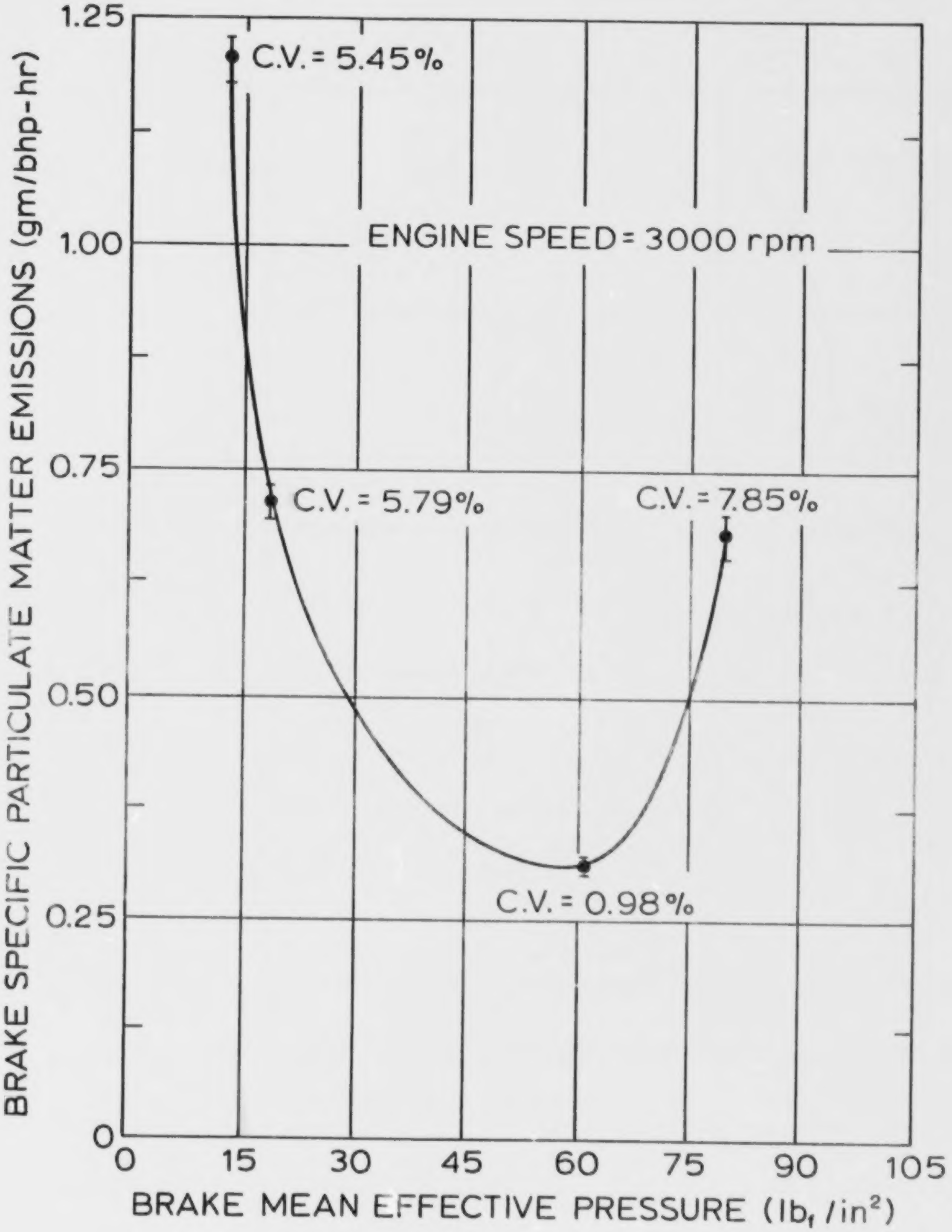
This shows the brake mean effective pressure, which is the load of the engine, for those of you who are not familiar with engine terminology, versus the brake specific particulate matter in grams per brake horsepower hour. Now, this is the total particulate that we collect on the sulfate filter before we analyze for the fraction that is the sulfate. We find that, at full load, this curve hooks up in terms of grams per brake horsepower; and, at light load, it hooks up with a minimum at about 60 percent roughly of full load conditions, would give us the minimum particulate in terms of the grams per hour divided by the brake horsepower, which is what we are trying to get out of an engine in terms of an output exhaust emissions over the output in terms of normalizing to the power that we are really looking for from an engineering viewpoint.

So, you can see at light load, to develop a light load duty cycle, we will get out a lot of particulate emissions; and its most efficient point is really out here, partly loaded, and it will be high levels here at full load conditions.

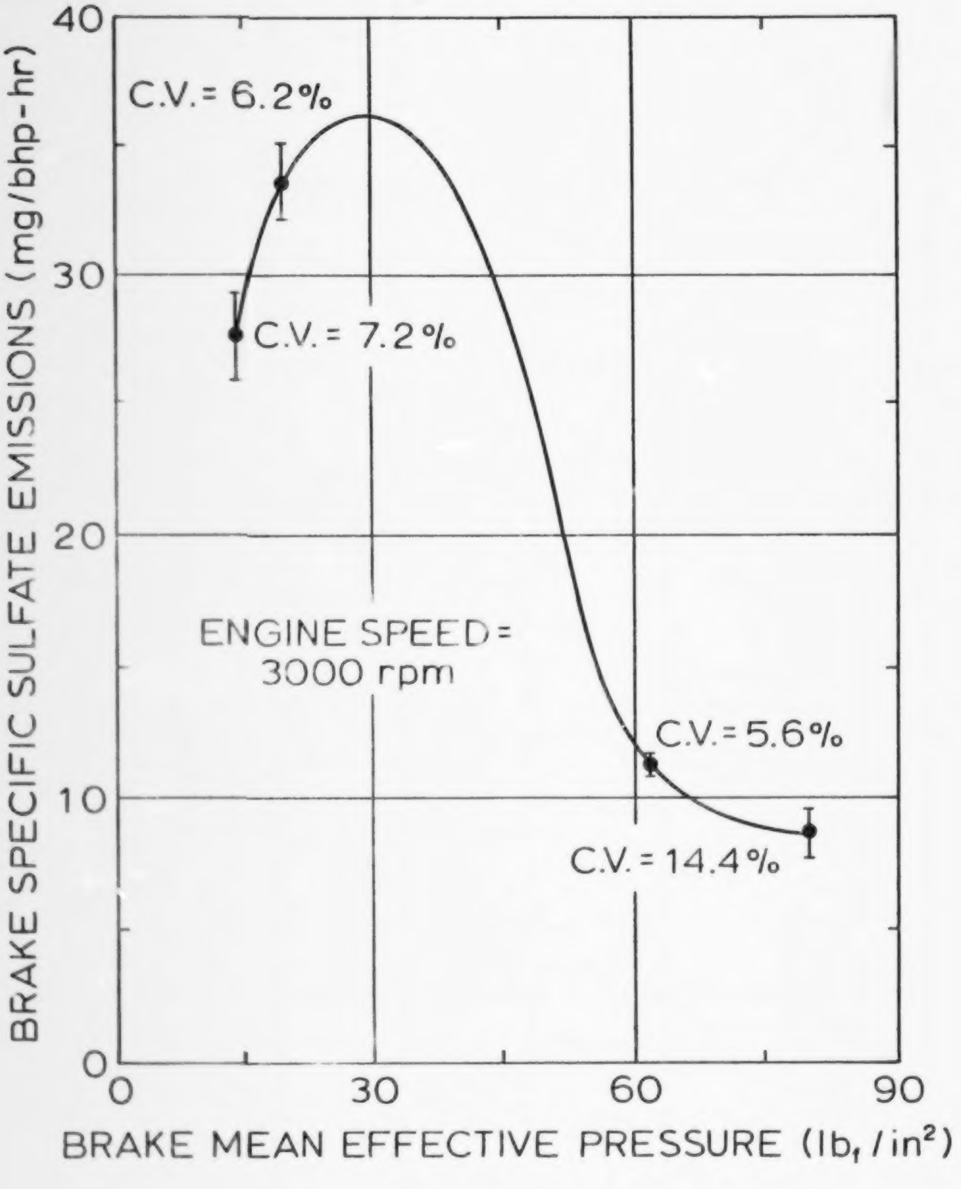
May I have the next slide? #15

What I have in the next slide, then, is the sulfate plotted versus brake mean effective pressure, the sulfate in milligrams per brake horsepower hour. We have some coefficient of variations from a number of repeats also indicated.

This is about in the range typically between 2 and 4 percent on a mass basis, based on the sulfur of the fuel converted to sulfate; and so, it is not a large amount that is converted to sulfate in the tunnel. This is tunnel measurements, but the reason that I raise the question is, when we get into the control, one of the control approaches is to use a catalyst; and so, we have to be


BRAKE SPECIFIC PARTICULATE MATTER EMISSIONS (gm/bhp-hr)
1.25
1.00
0.75
0.50
0.25
0
0
15
30
45
60
75
90
105
BRAKE MEAN EFFECTIVE PRESSURE (lb$_f$ /in^2)
ENGINE SPEED = 3000 rpm
C.V. = 5.45%
C.V. = 5.79%
C.V. = 7.85%
C.V. = 0.98%

SLIDE 14



BRAKE SPECIFIC SULFATE EMISSIONS (mg/bhp-hr)
40
30
20
10
0
0
30
60
90
BRAKE MEAN EFFECTIVE PRESSURE (lb_f/in^2)
C.V. = 6.2%
C.V. = 7.2%
ENGINE SPEED = 3000 rpm
C.V. = 5.6%
C.V. = 14.4%

SLIDE 15

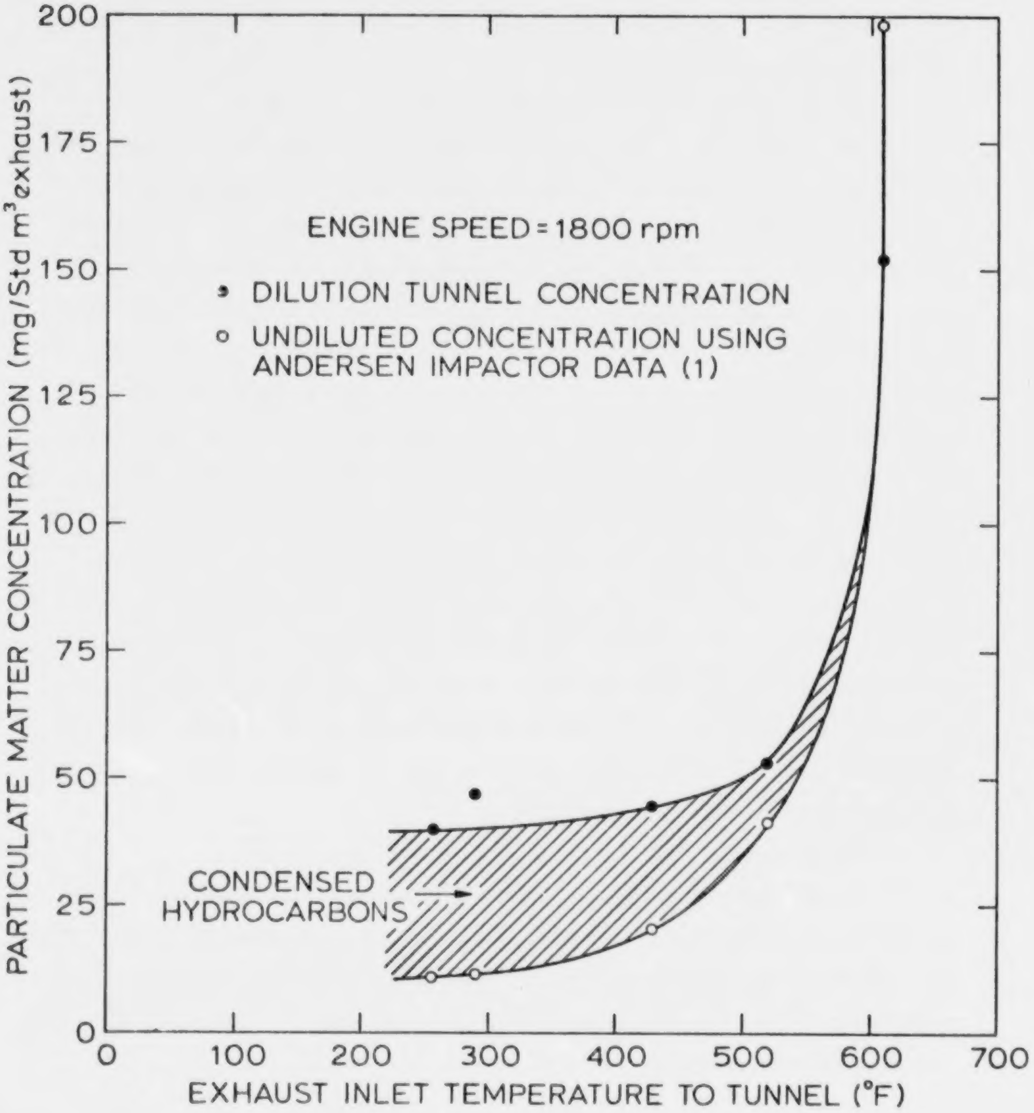
careful as we put a catalyst in the exhaust that we don't increase the amount of sulfate because of the higher levels of sulfur in diesel fuel as compared to gasoline fuel when we add on control devices, which we will be talking about this afternoon. That is why I wanted to raise this issue about measuring the sulfate. Probably in normal combustion systems without catalytic converters, you really don't have to go through measurements of sulfate because of the small amount converted.

Could I have the next slide, please? #16

The other thing that we have done with some of our data, we have plotted the exhaust inlet temperature to the tunnel and the particulate matter concentration in milligrams per standard meter cubed in the raw exhaust; and we have taken some of our earlier data that we had collected with the Andersen impactor. This is the total amount. If we sum it up on the Andersen in the undiluted exhaust and some of our recent sulfate -- it is measured with a different collection device. We have measured the fraction here with the sulfate filter and plotted that for these same load conditions for the same engine, and we find this increase, which we feel, and we are going through some filters now and getting the soluble fraction, and we think, and this is a hypothesis, that these are the condensed hydrocarbons that we think we collect in the tunnel, this mass increase, but we don't have data in terms of the soluble fraction or some other indirect evidence, such as carbon hydrogen nitrogen data or oxygen data that we can indirectly really pin this on these condensed hydrocarbons.

Could I have the next slide, please? #17

We are now working in terms of research, in terms of estab blishing techniques to reproducibly collect the organic compounds in dieselpparticulates, separate and isolate these organics, identify and try to go as quantitatively as we can in terms of the components of the sample.



200
175
150
125
100
75
50
25
0
PARTICULATE MATTER CONCENTRATION (mg/Std m³exhaust)
ENGINE SPEED = 1800 rpm
● DILUTION TUNNEL CONCENTRATION
○ UNDILUTED CONCENTRATION USING ANDERSEN IMPACTOR DATA (1)
CONDENSED HYDROCARBONS
0
100
200
300
400
500
600
700
EXHAUST INLET TEMPERATURE TO TUNNEL (°F)

SLIDE 16

ORGANIC COMPOUNDS IN DIESEL PARTICULATE MATTER

GOALS

1. ESTABLISH TECHNIQUES TO REPRODUCIBLY COLLECT THE ORGANIC COMPOUNDS ON DIESEL PARTICULATES.
2. SEPARATE AND ISOLATE ORGANICS.
3. IDENTIFY AND QUANTIFY COMPONENTS OF SAMPLE.

Could I have the next slide? #18

This is the technique that I showed you before in terms of the tunnel and the 8 by 10 filter that we collect our sample, and it is used as a probe sitting up in the tunnel to collect this diluted exhaust.

May I have the next slide? #19

We then take and extract the soluble organic fraction.

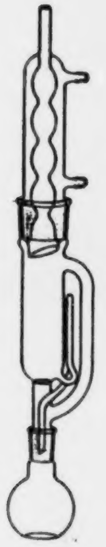
May I have the next slide, please? #20

I have taken some data from the Southwest Research Institute who have been doing a lot of this and the data are published. Our data really is not in shape yet. We are getting ready now, I think, to publish some of our soluble fraction data, but just to show you the kind of soluble fraction that comes from two different engines, I have taken these data, and this should be .1 percent sulfur, this was the fuel from the Hare SAE paper 76013, and at various loads and various speeds here, the rated speed and peak torque speed we have the percent organic solubles as a fraction of the total particulate, showing the numbers that you get. This is a Cummins engine. You see that there are differences, and we find ranges all the way from around 2 to as high in this case of up to 76 percent, and we have run some modes on the engine that take us up even higher than this in terms of the fraction that is soluble, and it obviously depends upon the load and the condition of the engine and the engine type, and there is obviously an interaction between the combustion process and the lubricant that enters in.

Could I have the next slide? #21

In this Southwest paper, they have gotten into this question of lubricating oil, and they have done a weight percent, a boiling fraction curve, and they have put in versus temperature here in degrees C and temperature in degrees F in this particular paper, a very interesting plot in terms of the range of fuels, in terms of the boiling fraction. They put in the paraffin, the normal paraffin boiling range by carbon number here, and they have shown that the r

HIGH VOLUME SAMPLER PICTURE IS
SHOWN IN SAE PAPER 780108 (SP 430)



SOXHLET
EXTRACTOR

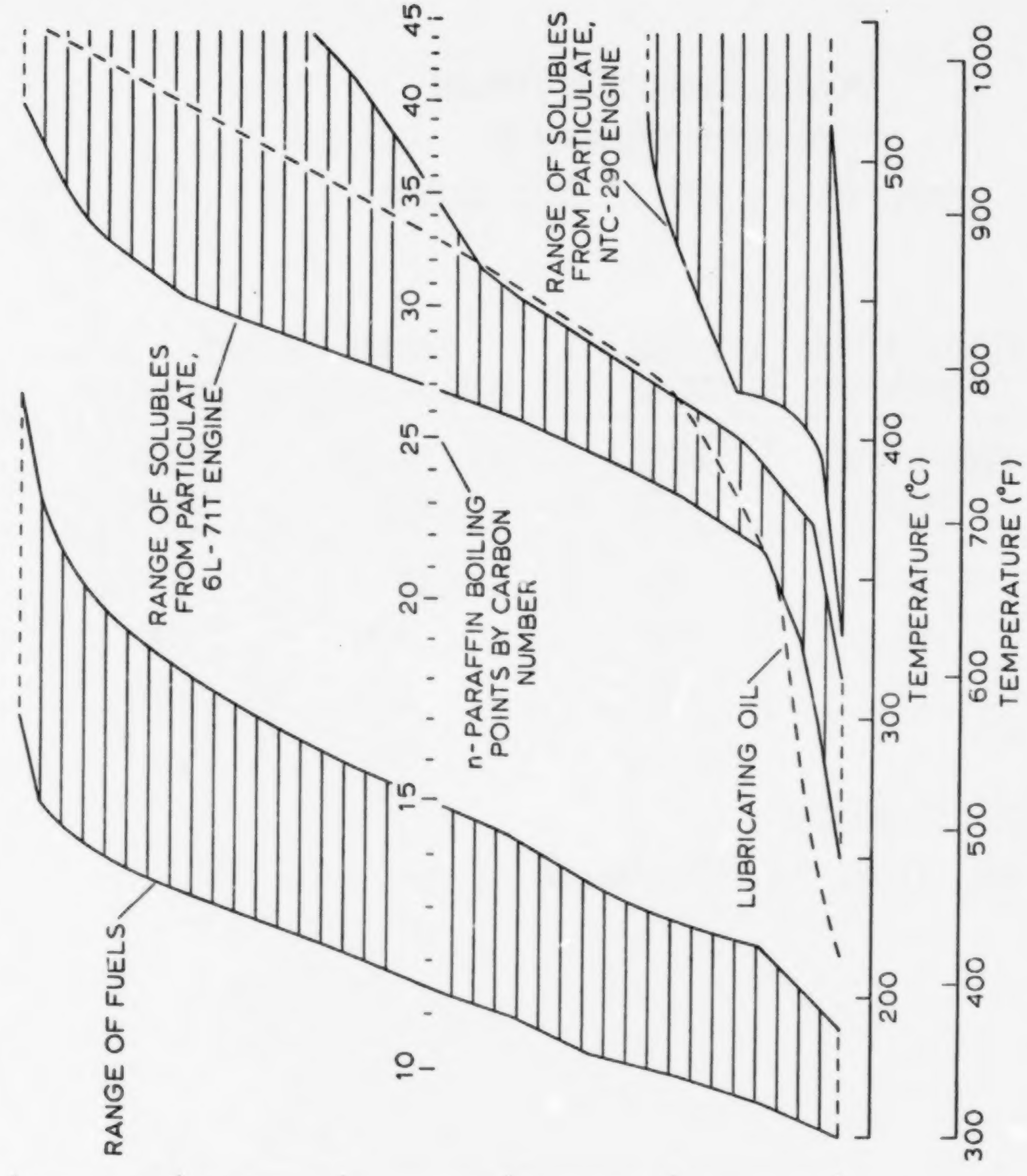
SLIDE 19

ORGANIC SOLUBLES AS PERCENT
OF TOTAL PARTICULATE
FOR FUEL C - 39°API, 0.10% SULFER*

	DETROIT DIESEL 2-STROKE, TURBOCHARGED, DI ENGINE		CUMMINS 4-STROKE TURBOCHARGED, DI ENGINE	
% FULL LOAD	PEAK TORQUE SPEED	RATED SPEED	PEAK TORQUE SPEED	RATED SPEED
0	64	57	16	14
50	52	76	7.4	16
100	32	67	2.8	(A)

(A) TOO SMALL TO MEASURE

*SOURCE: HARE, ET AL, SAE PAPER 760130



Source: Hare et al, SAE Paper No. 760130

SLIDE 21

the range of solubles from the General Motors 6L71T engine here, they have shown a curve for the lubricating oil and they have shown the characteristics of the 290 and have talked about the interaction in this paper between the particulate, between the fuel and also the lubricating oil and how there can be wide differences depending upon the lubricating oil system design of the engine in terms of this, and it also, if you read the paper, they could really not get up with their analytical techniques into these high carbon numbers here with the analytical techniques that they were using.

I think that this is the end of my slides. I have obviously gone through fairly rapidly because I know a number of you have probably read these papers. You are working in your own labs. You are familiar with the technique, but I thought it would be useful to just lay a foundation here in terms of what diesel particles are, how do we go about in the laboratory presently, the state-of-the-art, in terms of making these measurements, and so with that, I will close.

The next talk, we have a little switch. Dr. Begeman, I understand, was not able to be with us today, and we have substituting for him Jon Heuss from General Motors. He is going to talk about the Polynuclear Aromatic Content of Diesel Engine Exhaust, the CAPE-24 work from CRC.

MR. HEUSS: Thank you very much.

I would like to try to get us back on schedule. I only heard about 2 o'clock yesterday afternoon that I was going to be giving this as Charlie took sick. First, I would like to mention a little bit about Charlie Begeman who is, as I am, with the Environmental Science Department of the GM Research Laboratories. Charlie has been working in unregulated emissions and unregulated particulate emissions for 20 years or so. Many of you are probably familiar with the work that he and Joe Coluchi did over a number of years in the sixties, looking at polynuclear aromatics from engines and in the atmosphere.

Charlie took a couple of years off to study sulfate emissions and is now heavily back into diesel particulate emissions. He is, also, the group leader of a CRC project, which I would like to get into today.

The CRC, in case you are not familiar with it, is an organization sponsored by the Society of Automotive Engineers and the American Petroleum Institute that conducts cooperative research into factors which influence engines, fuels, and lubricants. About 10 years ago, they got into the air pollution business, formed a committee that had government representatives from what was then the predecessor of EPA, sponsored contract research into the nature and effects of vehicle emissions, in engineering, medical, and atmospheric areas.

The particular project I AM going to discuss is an investigation of the polynuclear aromatic content of diesel engine exhaust.

This particular project started in 1972, and it was essentially organized to determine PNA emissions from heavy duty diesel and gas turbine engines. The project group selected Gulf Research and Development as a contractor, and they were persuaded favorably on a proposal from Gulf that involved a new simple technique for sampling PNA's from undiluted exhaust on a hot chromosorb 102 absorbent which was indicated to have a high specificity for aromatic compounds. As Jim Pitts indicated, PNA's are reactive. Quite a few people have found that, even though not everybody in the literature says so; and this particular sampling technique did not work out. The method was subsequently dropped and replaced by a rather conventional cold filtration sampling system that bears some similarity to the one John was just mentioning.

The program, as it was envisioned, was for the emission measurement of benzo-a-pyrene, benzo-a-anthracene, and as many other specific PNA's as convenient from seven different heavy duty diesel engines. This was to be preceded by a period of validation of the proposed sampling and analytical procedures. Since you have to be able to measure something before you know much about it and, as Jim mentioned, some of these measurements are extremely difficult, the project has been involved for a number of years in the validation of the sampling and analytical procedures. It is still at that point at this time.

In trying to sample from undiluted exhaust the problems were that the BaP and BaA recovered were often extremely low, and this included recovery of added carbon 14 radioactive isotopes of BaP and BaA. The amounts recovered were very small, too small for accurate determination; and the recovery of the radioactive tracer was often only a few percent, indicating almost complete destruction in the sampling and analysis. So, if you tried to scale up using the loss of the radioactive tracer, you ended up with very large scale factors; and you had no confidence in the final numbers.

So, the project was then switched to a more conventional sampling and analysis procedure with a cold filter, a large dilution system, and improvements in the radioactive tracer ejection system. Even in this system, quite a bit of the radioactive PNA's are destroyed. However, a variety of specific experiments designed to see where in the system these losses may occur were carried out. A major portion of the tracers are destroyed by reaction with volatile constituents in the exhaust and on the filter and, probably, in the aerosol phase, confirming the kind of things that Jim has been discovering lately.

The group spent quite a bit of time in this effort. They were able to find certain conditions where they had less destruction and varied the dilution and found that indeed they could back calculate to a constant BaP and BaA emission rate. At this point, procedures for sampling and analysis of PNA in diesel engine exhaust looked promising.

The group decided, because of these many sampling problems, to sponsor a round robin test for reproducibility of BaP analysis in diesel exhaust from a number of laboratories. Samples were prepared by a number of laboratories. Extract of particulate matter captured on glass fiber filters were spiked with radioactive carbon 14 BaP. Aliquots were analyzed by five laboratories in two sets of round robin experiments.

The participating laboratories used the analytical techniques of their choice, but were expected to apply radioactive isotope dilution to compensate for analytical losses, if they could.

Four laboratories did this, and the coefficient of variation was 18 percent. So, we are still talking about considerable losses and variation in the numbers that you can get. A report documenting this study is in preparation, and it should be out in a couple of months.

The Gulf Research and Development effort has two reports out in NTIS.

The Gulf work was able to determine BaP and BaA emissions from one heavy duty diesel, and they ranged for BaP from 16 to 28 micrograms per kilogram of fuel burned, and for BaA from 16 to 68 micrograms per kilogram of fuel burned.

The project group recognizes that the complexities of this analytical scheme are in the process of being solved. So, the group has gone back to the original objective, which was to establish the emission rates of significant PNA's from several diesel engines and look at the effects of engine type, emission control modifications, engine operating conditions, and fuel and oil factors. Another request for proposal has been put out, and the contract group is in the process of evaluating a number of proposals at this point.

They have included, again, as a first step, the demonstration of the validity of the sampling and analysis techniques for PNA's and a variety of other potential carcinogens that may be later identified.

So, the contractor will have to spend a considerable amount of time validating the sample collection and analytical techniques: considering application of carbon 14 isotope tracers to compensate for

for losses, trying to measure the efficiency of the PNA recovered from engine exhaust, recovery from the soot after extraction, looking at effects of exhaust dilution on sample integrity, of sample storagee on sample integrity, and trying to look for artifact formation and to improve the precision.

That is the status of the project, and I think it,aggain, points out the complexities of dealing with some of these quite labile materials. We are trying to understand what the emissions are under conditions reasonably representative of the actual working engine. This is not a simple task.

PROF. JOHNSON: Thank you, John for a good overview.

I might also add, there is an SAE paper, presented at the last SAE meeting in February, that summarizes those two reports in briefer form.

Our next talk,is by Mr. Robert Gibbons of the Diesel Automobile Association. It is entitled, "Characterization of Emissions Characterization."

Mr. Gibbons?

MR. GIBBONS: Good morning. I am Robert Gibbons, President of the Diesel Automobile Association. We are an association of diesel car owners, diesel businesses, and a few diesel corporations.

I must say that I am not really prepared at this moment. I just walked in the door. We will speak later in the sessions. I just wanted to let people know who I am and to summarize in a sentence or two what we have found in looking at the literature on the issue of diesel particulates, the characterization of them. I think that we will learn a lot in these two days, but I think that the overwhelming fact that has to be at some point addressed is that we have been, it seems to us, treated to a cancer scare, and I say that in all seriousness. I think that we are subjected to tactics by certain groups and that this Conference should clear the air of that kind of thing.

Our consultant, Dr. Richard Pollack, will later in the Conference provide ample evidence that there has not been an increase in cancer since 1900 in the industrial nations when certain factors are taken into account.

So, for now, I would like to say that the Diesel Auto Association is very pleased to be here and to see exactly how we can straighten out this situation.

Thank you very much.

PROF. JOHNSON: Thank you, Mr. Gibbons.

We will go down then to Particulate Characterization Studies at Ford, and Jack Ninomiya from Ford will give the talk.

MR. NINOMIYA: Thank you very much, Dr. Johnson. I am Jack Ninomiya of Ford's Automotive Emissions and Fuel Economy Office.

When I agreed to present the sparse data we have at Ford on diesel particulates last week, I was told it was going to be a v very small workshop; so, I wouldn't have to be that well prepared. It turns out, from looking around the room here, that I see many distinguished and familiar faces. In a way, I am rather embarrassed with the amount of work we have done on diesel particulates.

Nevertheless, I would like to share this little bit of data with you this morning.

About two years ago, Ford's Advanced Engine Research group had a research contract with Southwest Research Institute to conduct engine mapping of diesel engines; and this work involved testing of a 2.1 liter Opel diesel engine, a four-cylinder Opel diesel, on an engine dynamometer under 11 different speed-load conditions. These are engine dynamometer, constant speed runs at different load conditions, and the purpose of this work was mainly to study the effects of different EGR rates and injection timing rates on exhaust emissions and fuel economy.

Along with these data, we have obtained some particulate mass emission data. So, I would like to share them with you.

May I have the first slide, please? #1

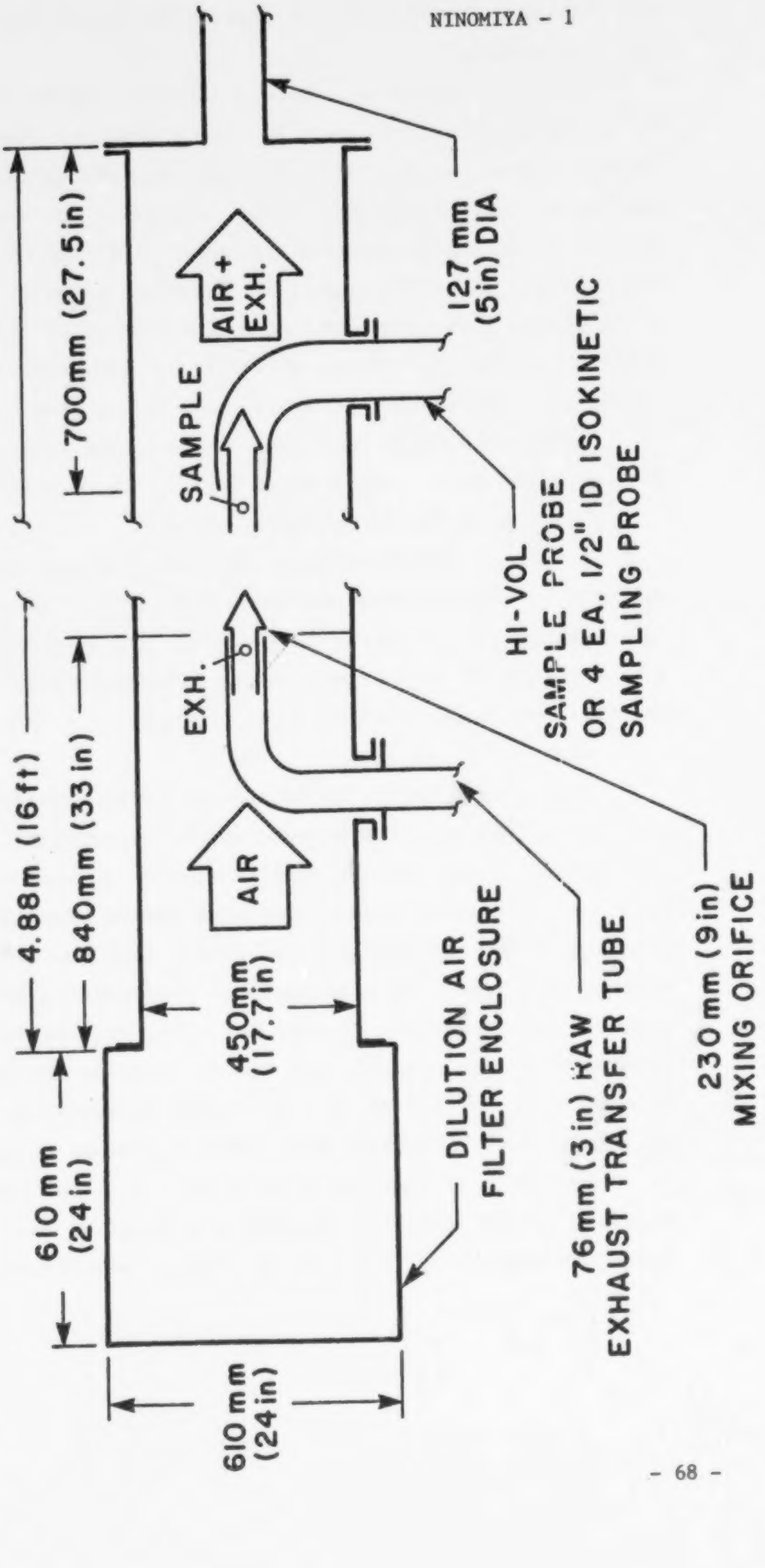
I will go pretty quickly. This is the sampling system that was used by the Southwest Research Institute. The sampling tunnel is connected to the engine dynamometer, and it involves the collecting of particles on a 47 millimeter fiberglass filter while the engine is run under different conditions.

Next slide, please? #2

What we did basically is to run the four-cylinder Opel engine at the baseline emission number, which is really a two gram NOx calibration. Based on the conditions that we have determined from this engine test, we have mapped what the emission would be like at one gram NOx calibration; and, under each one of these calibration strategies, we have measured particulates in this dilution tunnel. As you can see in this instance, calibrating NOx from two grams down to one gram did not really increase the particulate emissions; but on the other hand, smoke emissions as measured by the Public Health Service smoke meter increased about three times.

Now, in this case there was a zero EGR flow rate, and on this one, 19 percent; but subsequent studies we have conducted show that this is not the typical trend. Usually, as the EGR flow

PARTICULATE TUNNEL SCHEMATIC


610 mm (24 in)
610 mm (24 in)
4.88m (16 ft)
840 mm (33 in)
700 mm (27.5 in)
450 mm (17.7 in)
AIR
EXH.
SAMPLE
AIR + EXH.
DILUTION AIR FILTER ENCLOSURE
76 mm (3 in) RAW EXHAUST TRANSFER TUBE
230 mm (9 in) MIXING ORIFICE
HI-VOL SAMPLE PROBE OR 4 EA. 1/2" ID ISOKINETIC SAMPLING PROBE
127 mm (5 in) DIA

SMOKE, PARTICULATE AND SULFATE EMISSIONS FROM I-4 AND V-8 DIESEL ENGINES

AT BASELINE AND 1.0 gm/mi NOx CALIBRATIONS CVS-H

Based on Steady-State Engine Dynamometer Data Not Yet Confirmed By Vehicle Tests

	HC gm/mi	CO gm/mi	NOx gm/mi	CVS-H MPG	Smoke as Total Soot gm/mi	Parti- culate gm/mi	Average EGR %
I4 - 3000 lb.							
Baseline	0.37	1.14	1.27	31.5	0.08	0.57	0
1 gm/mi NOx	0.27	1.19	0.76	31.0	0.27	0.52	19
V8 - 4500 lb.							
Baseline	0.41	1.17	1.51	24.6	0.25	0.67	0
1 gm/mi NOx	0.31	3.02	0.75	23.0	0.76	1.14	29

rate increases, the particulate mass emission rate increases, also.

Now, taking this data from this four-cylinder diesel engine, we have projected through a mapping technique what would be the emission trends of a V8 diesel. I should also mention that, although this is an engine dynamometer work, we can simulate various vehicle weights, so that, in the case of a four-cylinder diesel, we have simulated the emissions of a 3000 pound vehicle, and, in the case of a V8, we have simulated a 4500 pound vehicle.

On a V8 simulation, the actual measure of the particulate emission rate is doubled by increasing the EGR rate from zero to 29 percent.

May I have the next slide, please? #3

This is just the summary of the data that was shown on a previous table. From zero to 20 percent EGR on this set of data, there appears to be no significant effect on particulate mass emissions; but as you increase the EGR flow rate past 20 percent, there is a dramatic increase in particulate mass emissions.

Next slide, please? #4

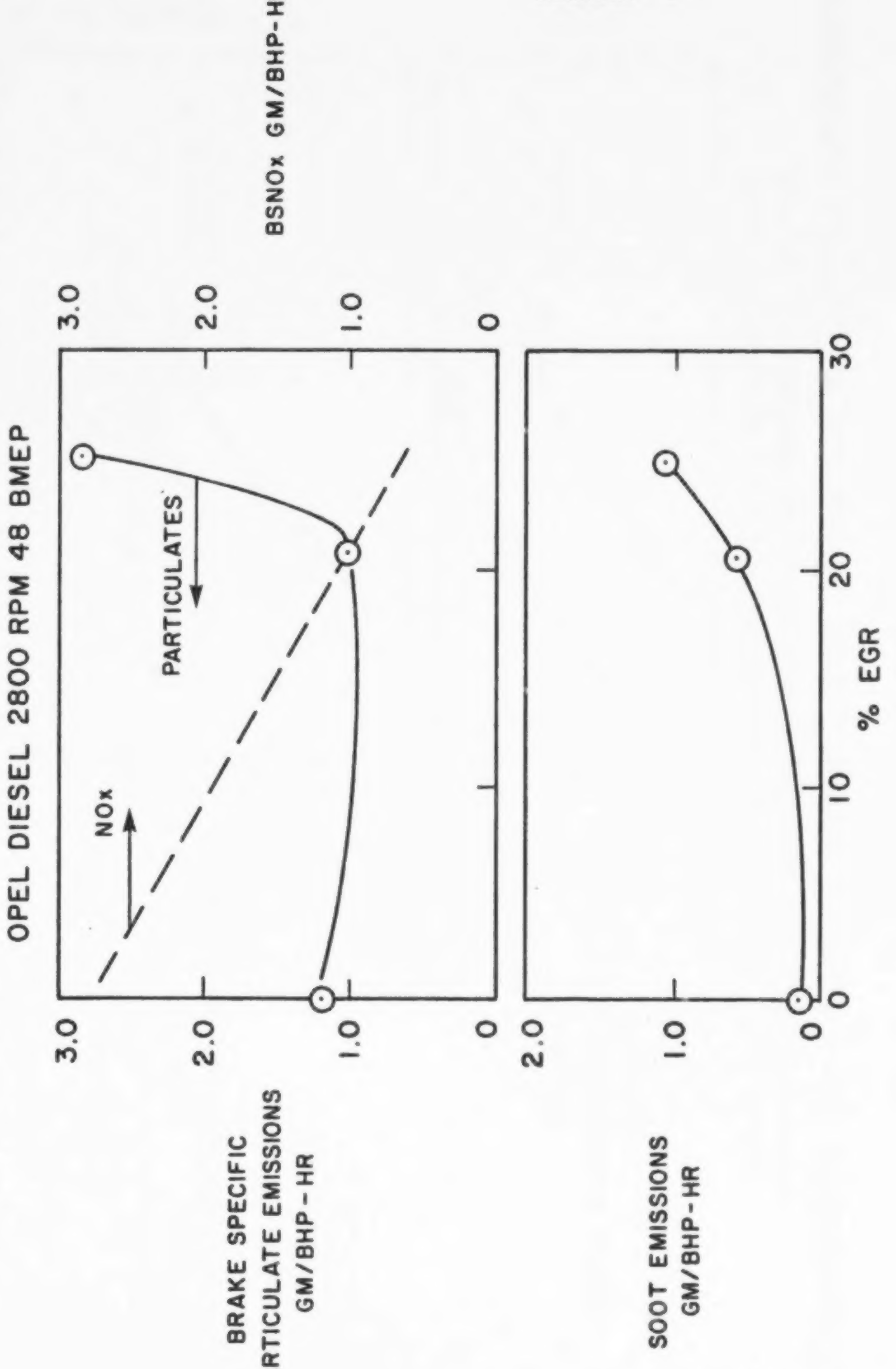
This is the effect of engine calibration in respect to NOx on particulate mass emissions. For the four-cylinder engine projection, I showed you earlier that there was not significant difference between one gram and two gram NOx calibrations; but for the V8 projection, decreasing the NOx emissions dramatically increased the particulate emissions.

Next slide, please? #5

That is all of the diesel particulate emission data that we have at Ford, but I would like to show you, or rather, to put these data in some perspective.

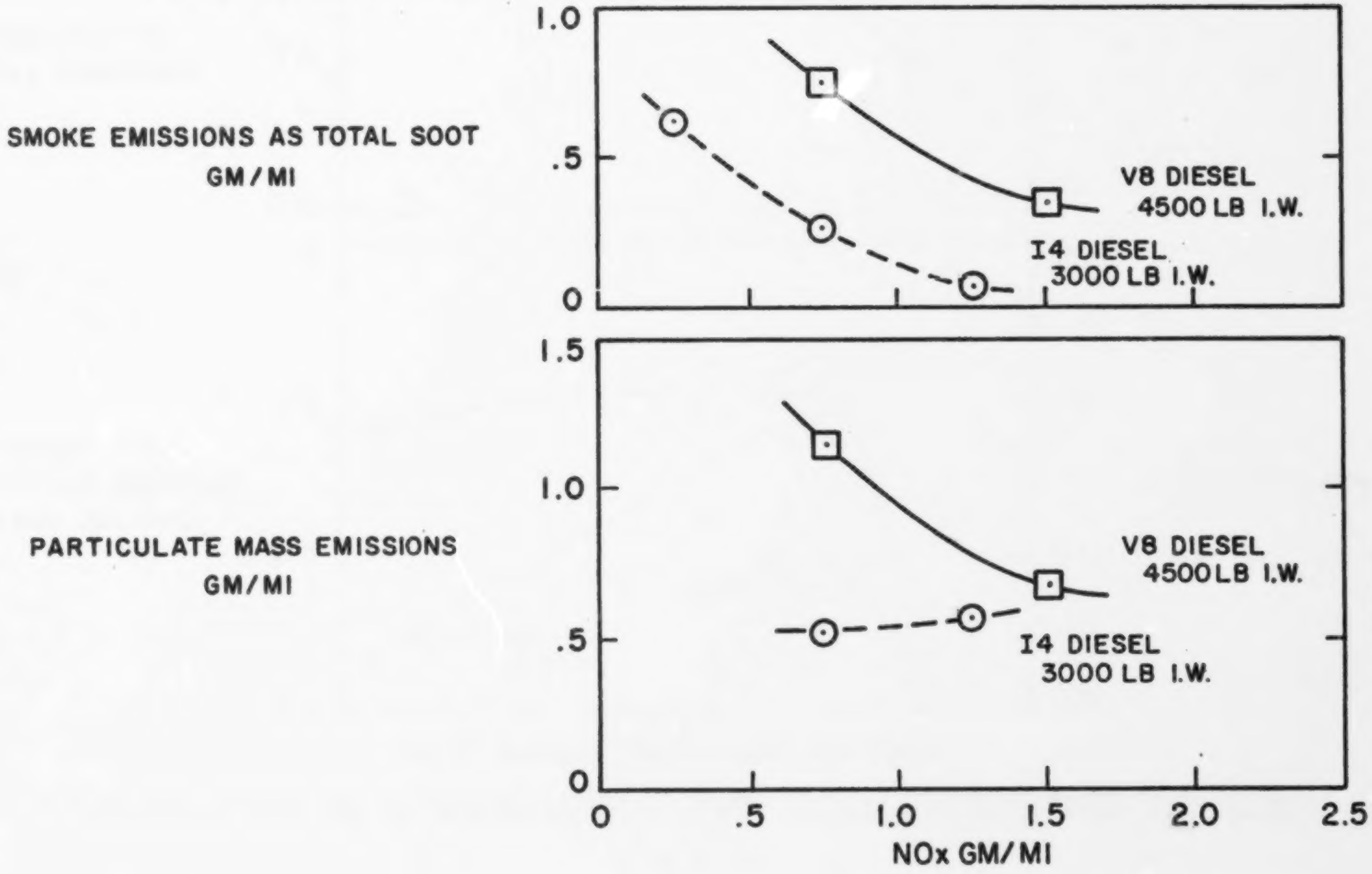
In addition, to the diesel mapping work, we have conducted at Southwest, we have run two diesel cars in-house. Now, these are actual chassis dynamometer diesel car testing. We have tested a Mercedes 240D and Opel 2.1 liter diesel under a 55 miles an hour

COMPARISON OF PARTICULATE AND SOOT EMISSIONS VS EGR



COMPARISON OF OPTICAL SMOKE AND PARTICULATE MASS EMISSIONS

CVS-H PROJECTIONS BASED ON STEADY STATE DYNAMOMETER DATA FROM OPEL DIESEL WITH EGR AND MODULATED INJECTION TIMING



NINOMIYA - 4

APPROXIMATE PARTICULATE MASS EMISSION RATES

Ford Mustang 302 CID, non-catalyst unleaded gasoline 1970 FTP	10-50 mg/mi
Ford Torino 302 CID, non-catalyst leaded gasoline (3.0 gm/gal TEL) 1970 FTP	300 mg/mi
Ford F-250 460 CID PROCO, non-catalyst unleaded gasoline 30 mph steady speed	50-60 mg/mi
Mercedes 240-D and Opel 2.1L diesel cars	200-500 mg/mi

steady-speed condition, and we have so far obtained the data of 200 to 500 milligrams per mile.

Now, the top two, Ford Mustang and Ford Torino, these are the data we obtained about seven years ago during the push to measure the tetraethyl lead particulates from gasoline engines. We have done a lot of work in this area; and just to show you the difference, a gasoline engine non-catalyst system using unleaded gasoline, using 1970 FTP -- this is a seven mode-seven cycle test -- we have measured about 10 to 15 milligrams of particulates.

Again, a non-catalyst system using a leaded gasoline, using three grams per gallon of tetraethyl lead, emitted about 300 milligrams of particulates per mile, so that the emission rate of a gasoline engine using leaded fuel is about comparable to that of small diesel engines.

So far, we have run only two tests on Ford's PROCO engine. This PROCO engine was installed in an F250 pickup truck which operated on unleaded gasoline. Under a steady-state speed of about 30 miles per hour, we have measured about 50 to 60 milligrams per mile of particulates, so that we feel that the particulate emissions from PROCO is about an order of magnitude lower than those from diesels.

Thank you very much.

PROF. JOHNSON: Thank you, Jack.

We will now go back to the Particulate Measurements in Different Engine Types and Their Hydrocarbon Contents. Mr. Richard W. Wheeler from Ricardo.

MR. WHEELER: Good morning, ladies and gentlemen.

Well, I expect some of you know the organization I come from and will be thinking, well, here is somebody who is going to be a total apologist for the diesel engine, being that many of the diesel engines, the light duty diesel engines are on the road are based on our fundamental design, which Sir Harry Ricardo produced way back in the early thirties, that is the swirl or Comet chamber diesel engine. It is not, of course, the only light duty diesel combustion chamber; another type, the prechamber, has a fine example in widespread use.

However, Ricardo is not only concerned with diesel engines. We are concerned with stratified charge engines and, also, with the latest high compression gasoline engines; and the battle is on. There is a general assumption that the diesel is the only engine that will give fuel economy. This is not necessarily so, the reason being that the diesel engine has been developed for 75 or more years for economy only; and this is a point that I think a lot of people miss, development has been entirely for economy for the diesel. Everything else has gone by the board, and anybody who drives up British motorways will see exactly how far it has gone by the board. The high compression gasoline engine has been developed for other more sophisticated uses, and economy has gone by the board; and I hesitate to say that with the emission legislation in the States, economy has even more gone by the board. Thus, due to its uneven development, the diesel engine now has to fight itself out of the particulate crunch and the gasoline engine out of its bad fuel consumption crunch. We are, thus, putting our eggs in both baskets; and on the diesel particulate side, we started some years ago with a very practical program which was sponsored by a large chemical group in Europe where we were asked to see if it was possible to filter the soot out of diesel exhaust and to get rid of it.

To do that, we were forced to do a certain amount of development of techniques. It did not take us long to show that the normal methods, which used things like Hartridge meters, U. S. Public Health Service meters, and Bosch meters, were not a bit of good for this job. It took us about a year to really prove that one; and so, we were then forced into developing particulates measurement procedures.

The first slide is a cartoon showing a British gentleman standing by a lamppost waiting for a bus, and he is not really complaining about particulates. I think the point is that an American gentleman standing by a similar lamppost at the present has never smelled such a thing because, for one thing, that stack would be vertical with a high plume. In fact, I have not recently really smelled a diesel engine in the U. S. A., but the gentleman by the lamppost, with typical British phlegm, is not protesting. #1

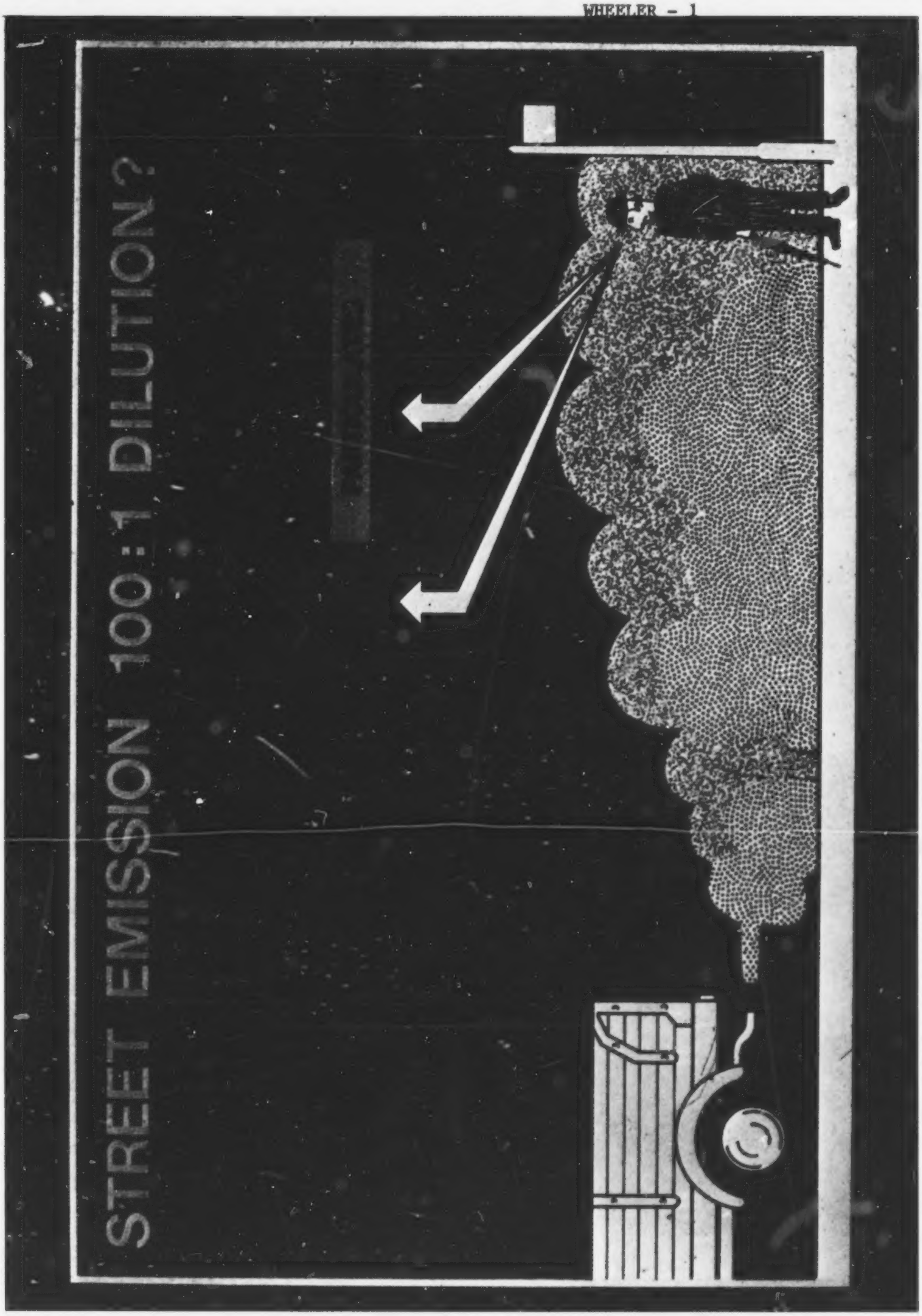
Although he is not protesting, his lungs are being affected, as earlier speakers have suggested; and he is being affected by particulates in the main and also by the hydrocarbons which are volatile within those particulates. Thus, we had to develop for this program some years ago, ideas which led us along the lines which John Johnson has so lucidly described; but we are just practical engineers, and we wanted something simple which engineers could do. We did not want chemical technology in the laboratory. The last person we wanted to get in a diesel laboratory was a wet chemist because they don't match together with the low technology approach of diesel manufacturing.

So, we had to develop simple techniques, as simple as our familiar analyzers.

Figure 2 shows the problem which we were facing, and which I mentioned just now, of the diesel's particulates. This is a good car. It is an Opel Diesel. That is a typical paper that comes from it holding the total soot from just 200 yards of driving.

Figure 3 shows the paper from a British Ford Cortina. It is typical of any non-catalyst car, and you can see that the paper here is soot free. That is what the battle is all about.

The first problem we faced was what dilution ratio we should use in our tests. I put at the top of Figure 1 100 to 1 dilution, which is the sort of dilution that our panels of untrained observers seem to suggest is where they would begin to get annoyed when we



STREET EMISSION 100:1 DILUTION?

WHEELER - P

CORTINA
1.3 L
SN

do our odor work; but, as John Johnson was saying, we have this problem of how do we get a realistic sample from exhaust at 100 to 1 dilution. In France, some people did pavement samples and came up with 2000 to 1. I am sure that none of our panels would ever complain of a diesel at 2000:1, but other people in Japan believe that 30 or 40 to 1 is a level at which the human nose will start complaining.

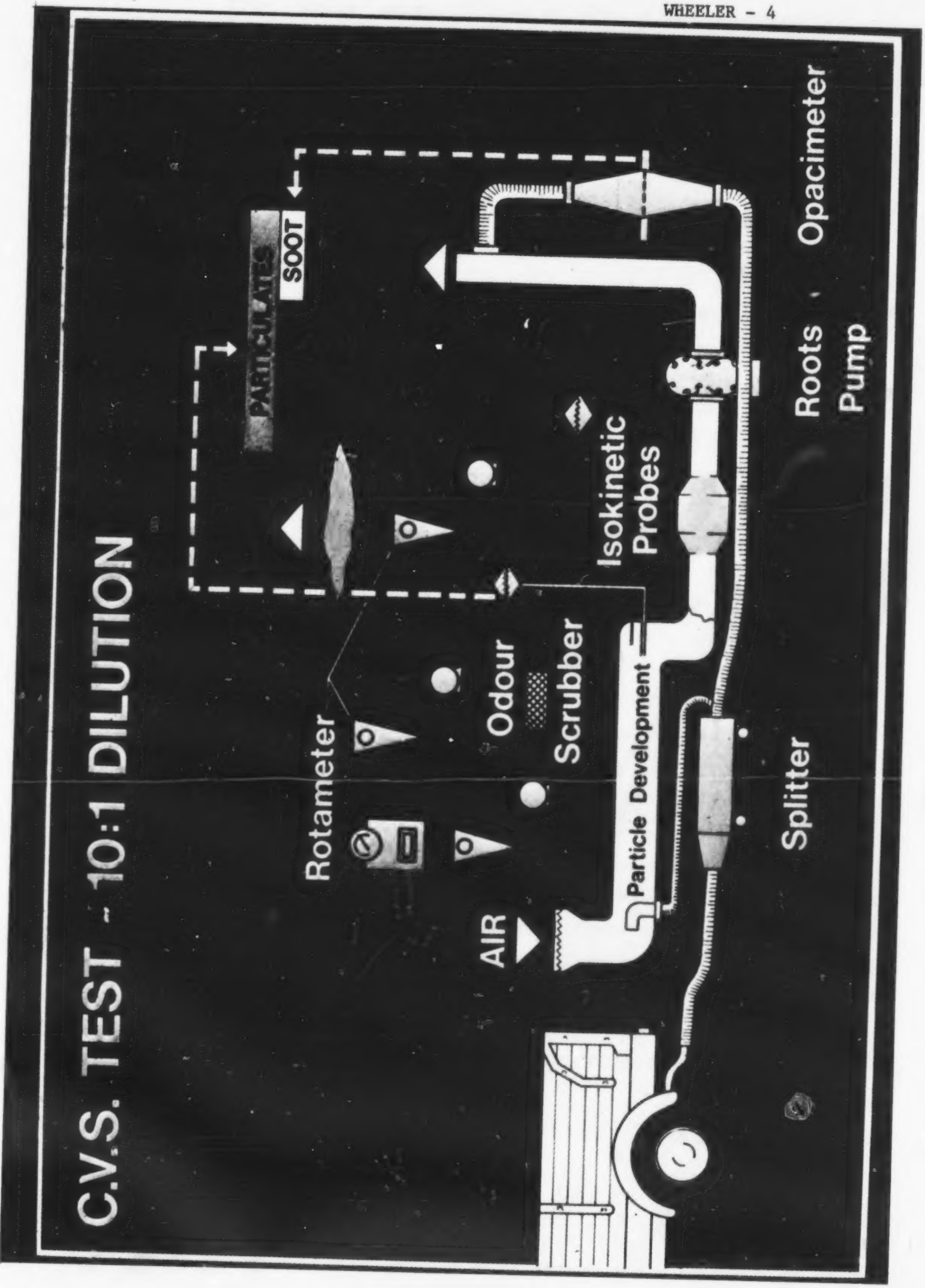
Bear in mind that the human nose is a peak height analyzer and not an integrator. However, your lung is the integrator; but you don't know the integral value until it is too late.

Figure 4 shows how we simulated, as far as possible, the conditions in Figure 1; and, as John Johnson said, we were forced to splitters right away. We just could not get the tunnel sizes in our laboratories.

We came up with tunnel sizes of eight to 12 inches diameter, with a length of 10 diameters. We feel that, possibly, 5 to 1 might be adequate; but anyway, 10 to 1 at the moment seems reasonable. We connected that to a standard CVS equipment. It all adds up to a fairly expensive apparatus. In Europe, many diesel manufacturers are very small companies, and they really don't want to go spending too much money on gear. So, again we felt that we had to perhaps improve on this situation.

However, from this tunnel with the isokinetic probe, we could get our total particulates. We could put an opacimeter on the major blowoff of the split; and from the cold bag in the CVS equipment, we could get the cold hydrocarbon.

Now, this is a point we like to make, that we don't think heated FID is at all fair to the diesel engine. It is an unrealistic procedure. You don't breathe hydrocarbons at a temperature of 190 degrees C. We believe that the moment you are talking about a particulates law, you have got to drop heated FID; and you must go to a fairer procedure because, of course, you are faced with the fact that particulates contain some of your heated FID hydrocarbons.



C.V.S. TEST - 10:1 DILUTION

To carry out our program on soot filtering, which I will describe in the next session, we developed this simple piece of gear. (Figure 5) It pushes in between engines. We do not use a CVS trolley but a simple centrifugal blower, as shown, running at 350 cfm. The filters are 8" x 6" glass fibre and are flowed at 3.5 cfm, and so recover 1% of the total particulate. The whole thing is about 12 feet long, and it is very cheap.

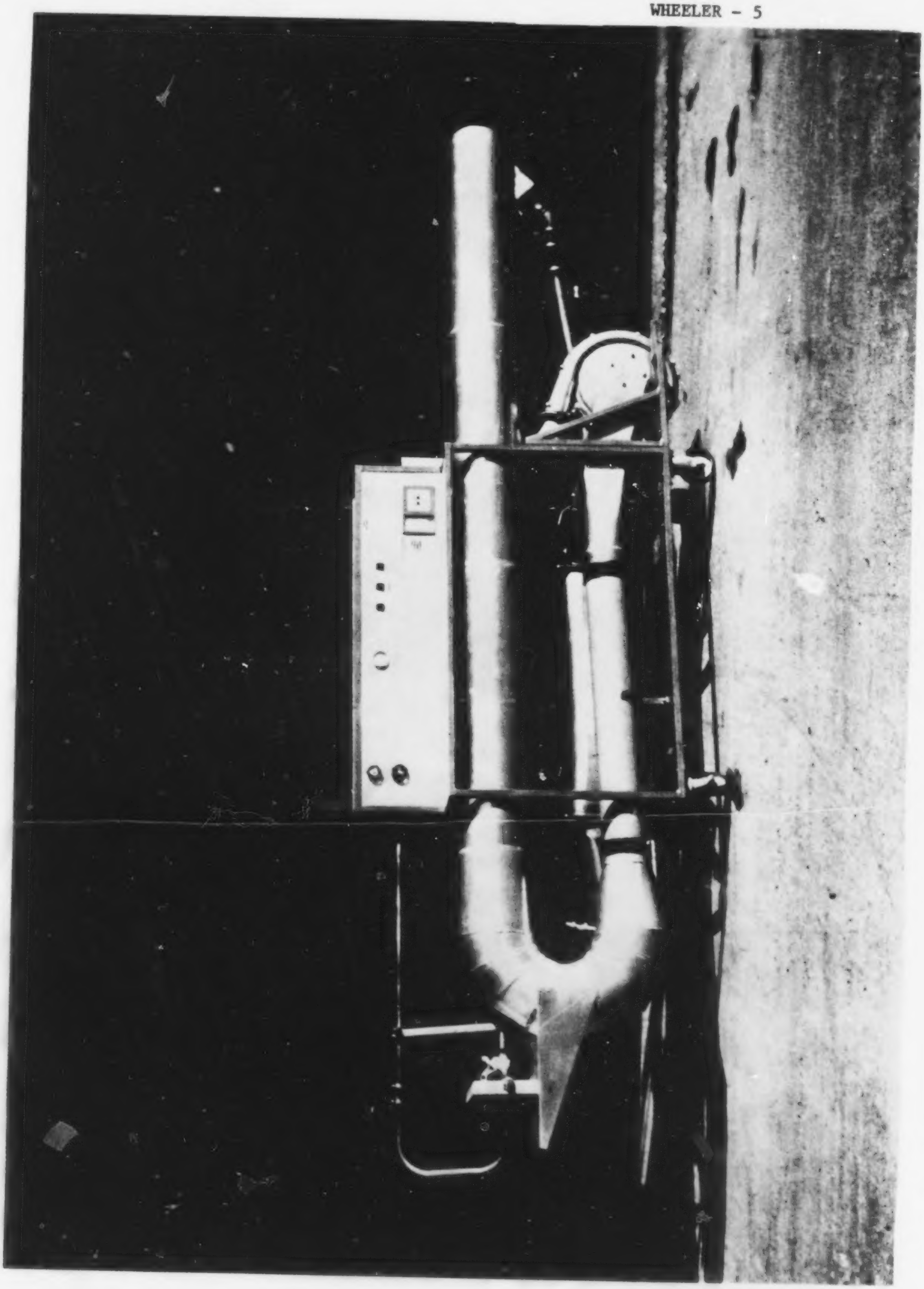
The next slide, Figure 6, shows the back of the splitter. We could not get any design to split properly over the complete range of the 13 mode cycle which is what we were using at the time without having a water cooled splitter.

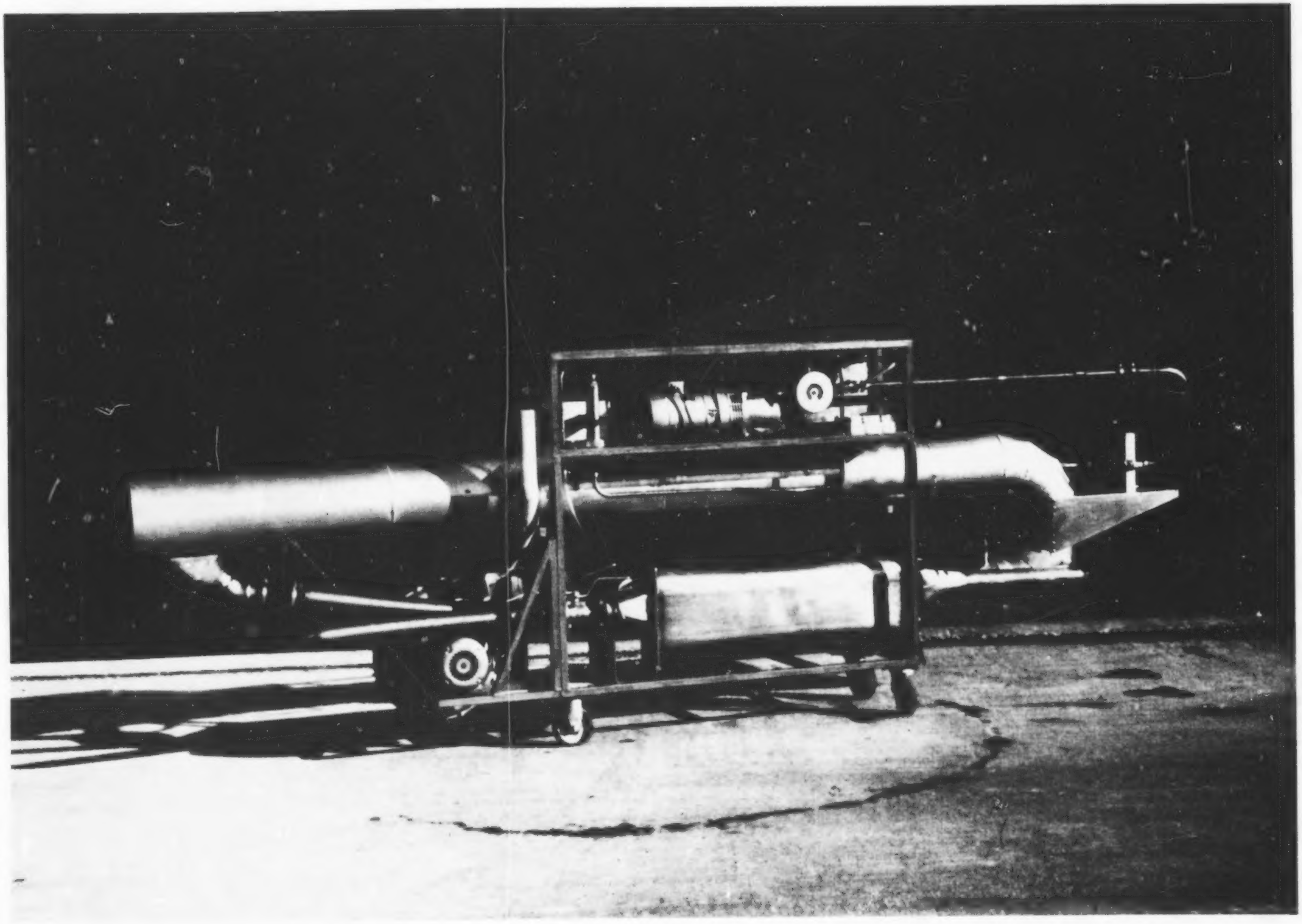
Now, we showed that, in the main, this water cooled splitter split perfectly well; also, it split particulates well, except at very light loads, when we began to get losses. The splitter is a typical water heat exchanger with a collection of pies three feet long which you connect equally to two outlets. That is just a simple splitter in which you throw half of your exhaust away and allows engines up to 6 L to be tested.

You can prove the perfection of the split by just reversing the two pipes on a steady engine state; and if you measure NOx and you get the same answer on your chemiluminescent analyzer, whichever split is connected, then you have a good split.

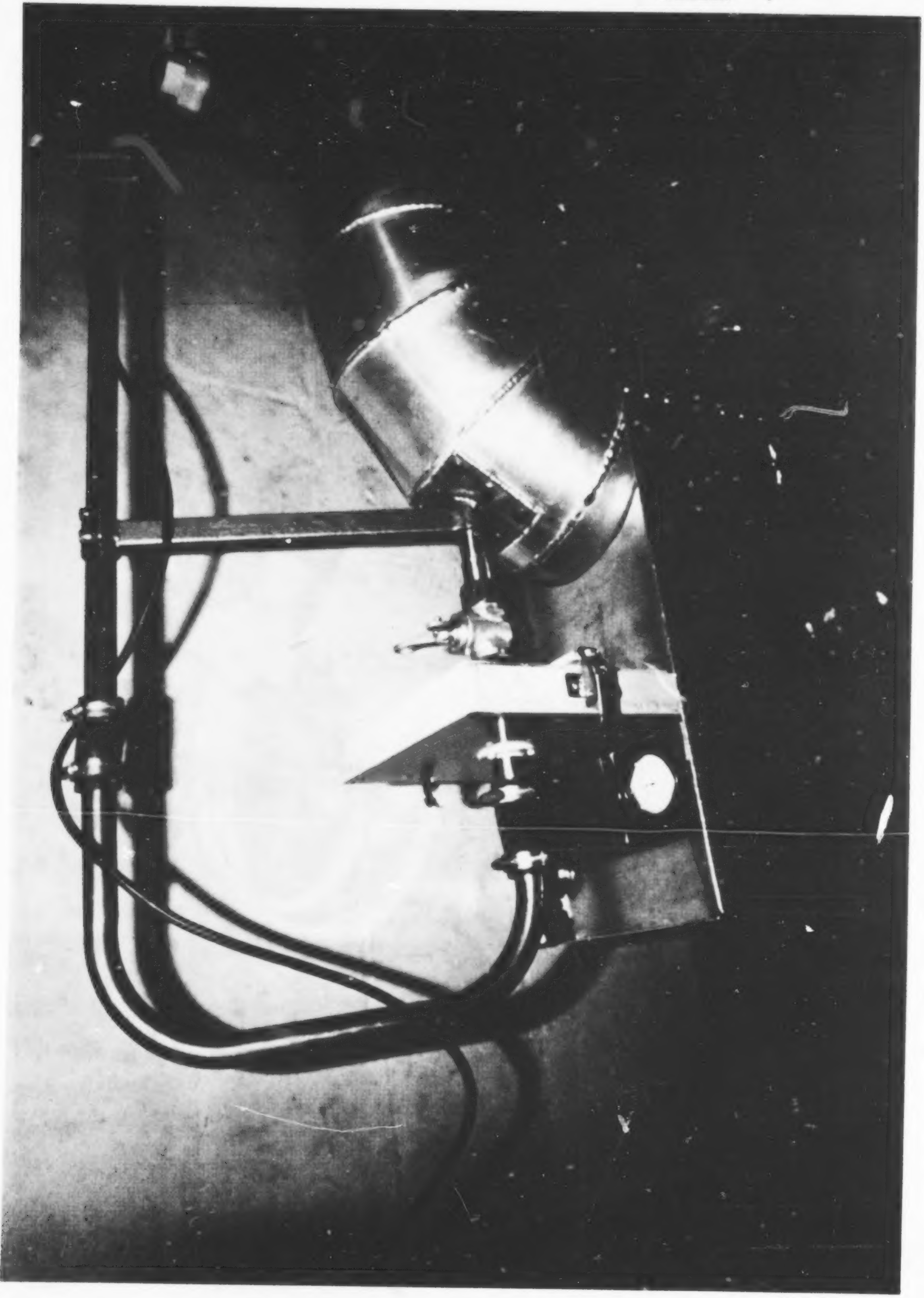
Figure 7 shows the end of the tunnel and the filter holder with its pipework.

Figure 8 shows the splitter that we started with, and it is one now that we are not too keen on. It gives a beautiful split. You can get perfection of split right down to light loads up to full load with this water cooled splitter; but, unfortunately, the water cooling tends to promote thermal precipitation, and, in fact, there is no way of stopping it, being a thermal precipitator. We found that any slightly cold area in the system tends to thermally precipitate soot. That is one thing about diesel particulates. They have a great attraction to surfaces and enormous suction to them.





WHEELER - 7



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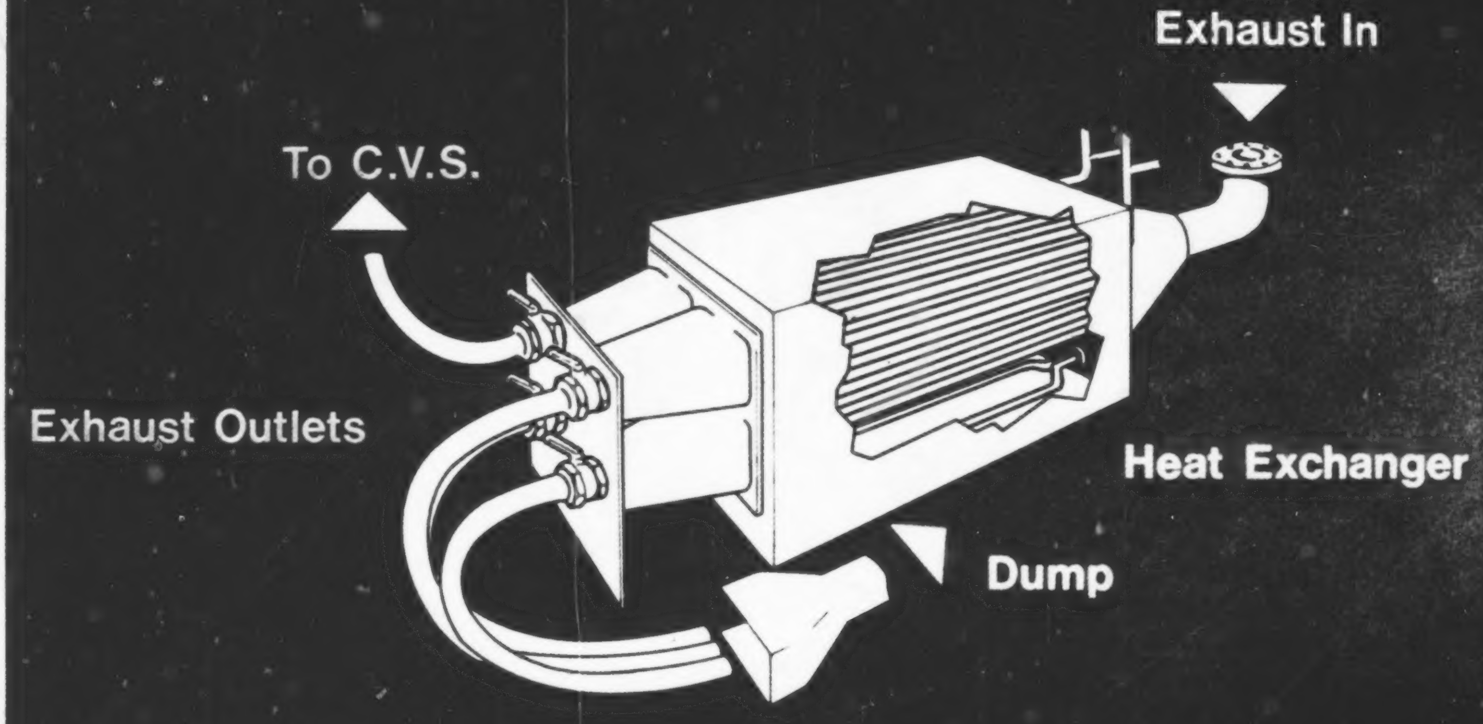
EXHAUST SPLITTER



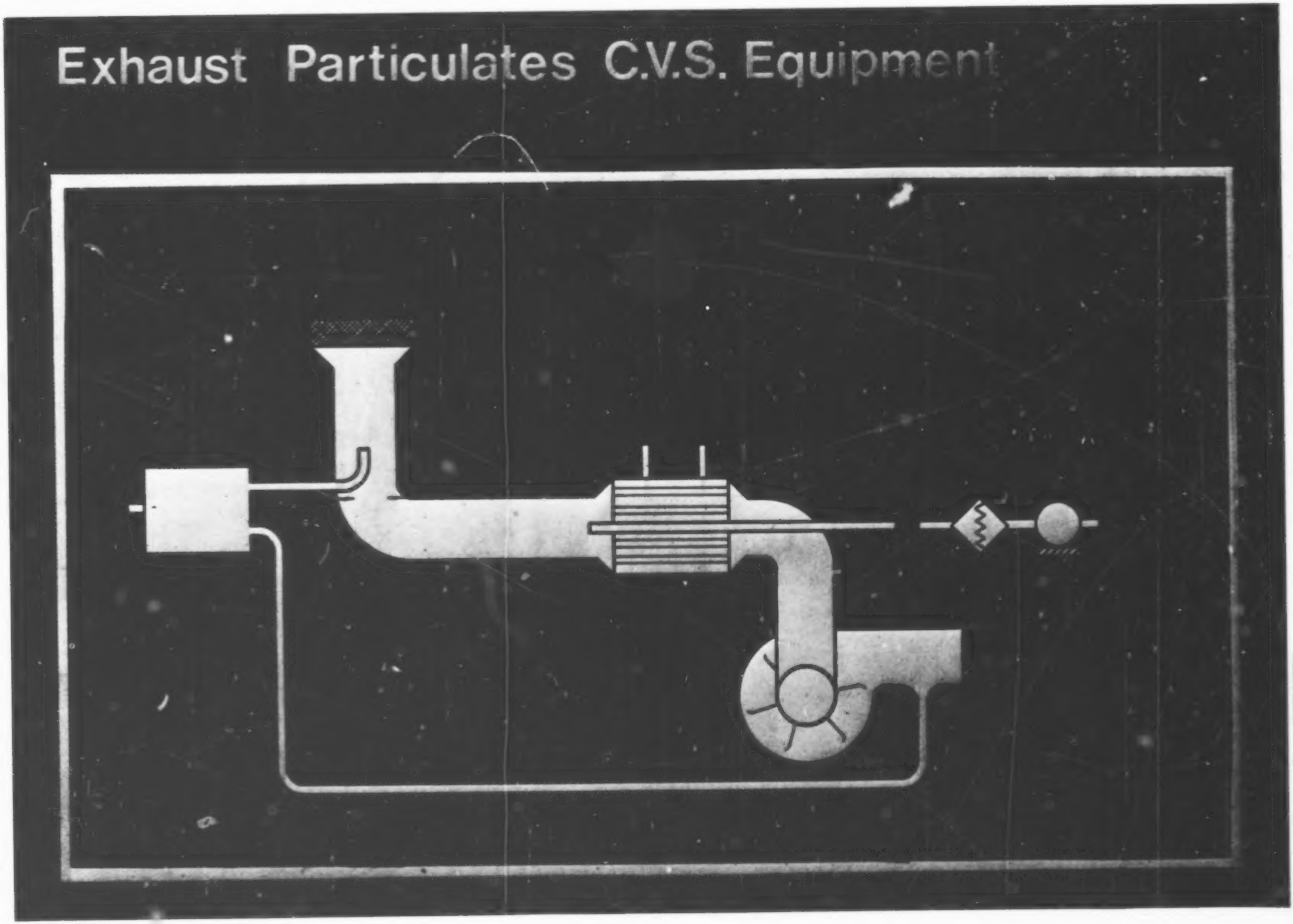
We have shown this extensively in odor work where we have tried to trap transient odors in plastic bags; and, however rapidly you handle the material, it flies onto the plastic, and you lose it. So, this is a warning against any cold surfaces or convoluted piping between the engine and the CVS tunnel. It is a big trap. Many agglomerates of soot come out here and can be shaken out during later modes giving false values.

The system needs developing from this simplistic one which I showed, and there are many ways to go. We have a program with EPA in which we are looking at a number of alternatives. Figure 9 shows a possible one in which you cool the sample. You need to cool the input; otherwise, the blower throughput alters with the temperature. It can be got over, I think, in the next Figure 10, where, in fact, you can have a temperature controller on the inlet in which a diverter valve diverts cool or hot air; and then, if you have a quick response control mechanism, this rather awkward cooler in front of the blower is not needed.

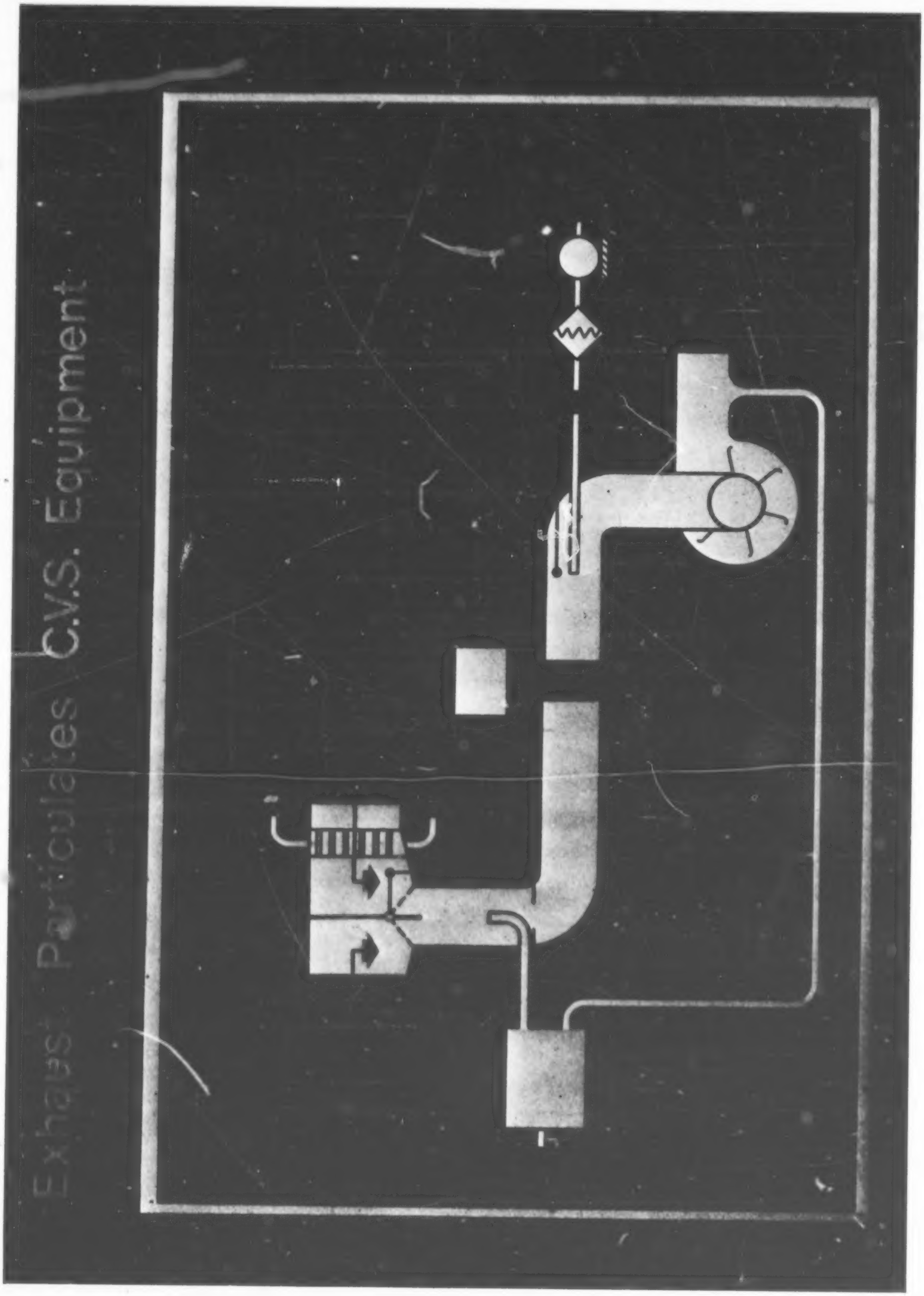
The tendency in the business now is not to use a complicated system like this but just to have a cooler, as on the standard CVS, and to have a maximum temperature which, at the moment, is being talked of as 125 degrees F as the maximum temperature allowable at the filter point.

There are possible ways of altering the pickup of hydrocarbons on the filter by adjusting the temperatures which you use here. This is again a point which we are looking at as to just what hydrocarbon gets adsorbed on the soot and what goes through it into this further system.

This is going to be quite an important point because it seems really that we have to be fair to the diesel and let the smog-forming volatile hydrocarbons go through the cold filter and be captured later, and the other materials, which are toxic in different ways, are to be captured and possibly retrieved from the filter.



Exhaust Particulates C.V.S. Equipment



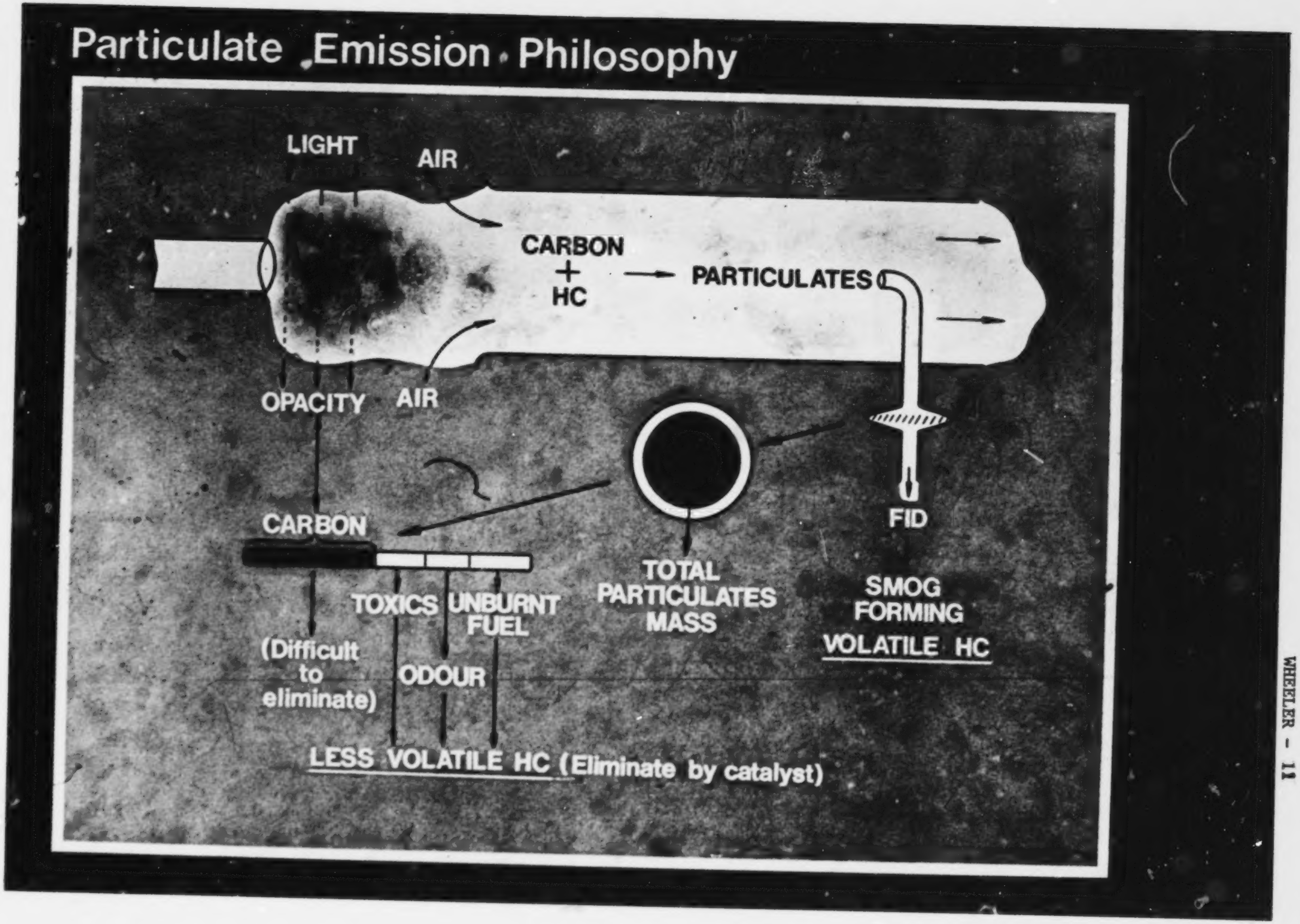
Exhaust Particulates C.V.S. Equipment

The philosophy that we developed after quite a lot of this work is shown in Figure 11. The diesel exhaust is emitting soot, which has opacity. We make use of that at present. It then is diluted with air; and at some point, the carbon and the hydrocarbons react together and adsorb or absord and give particulates which are filtered.on a filter paper, as shown. The proposal is that we should measure the weight of that paper and get a total particulate mass.

This may not be a very good way of developing diesel engines. It may somewhat inhibit the development of diesels from the practical engineer's point because we are talking of a multiphase system here. The carbon part of the particulate is very difficult material to deal with. Once you have got it, it is difficult to get rid of. You have then got the hydrocarbons, a galaxy of different carbon number hydrocarbons, some of which I would label toxic, some just odorous, maybe oxygenates, and some are just unburned fuel. So, those can be dealt with. There is a chance we can deal with them both by engine modifications and by exhaust catalysis.

We have already heard John Johnson mention the fact that by a catalyst these very specific toxic materials need only to be altered by a small amount, possibly to destroy them. We need to prove this, of course. The suggestion is that this is a vital thing that we should prove very quickly. Then we are left with this awkward problem of the carbon, which really may be only a hazard to the amenities. I would hesitate to say that it was non-toxic because you would have suggested that asbestos was non-toxic; but that is a question which, again, we must look into very urgently because soot is the difficult one to get rid of. We believe that there are ways of getting rid of it, which I will go into in the next session, and I will leave that now.

So, how do we look at the hydrocarbons that are in this soot. I said we did not want chemists in the laboratory. Well, I am not saying that methods of looking at these hydrocarbons in the soot



Particulate Emission Philosophy

LIGHT

AIR

CARBON + HC → PARTICULATES

AIR

OPACITY

CARBON

(Difficult to eliminate)

TOXICS

UNBURNT FUEL

ODOUR

LESS VOLATILE HC (Eliminate by catalyst)

TOTAL PARTICULATES MASS

FID

SMOG FORMING VOLATILE HC

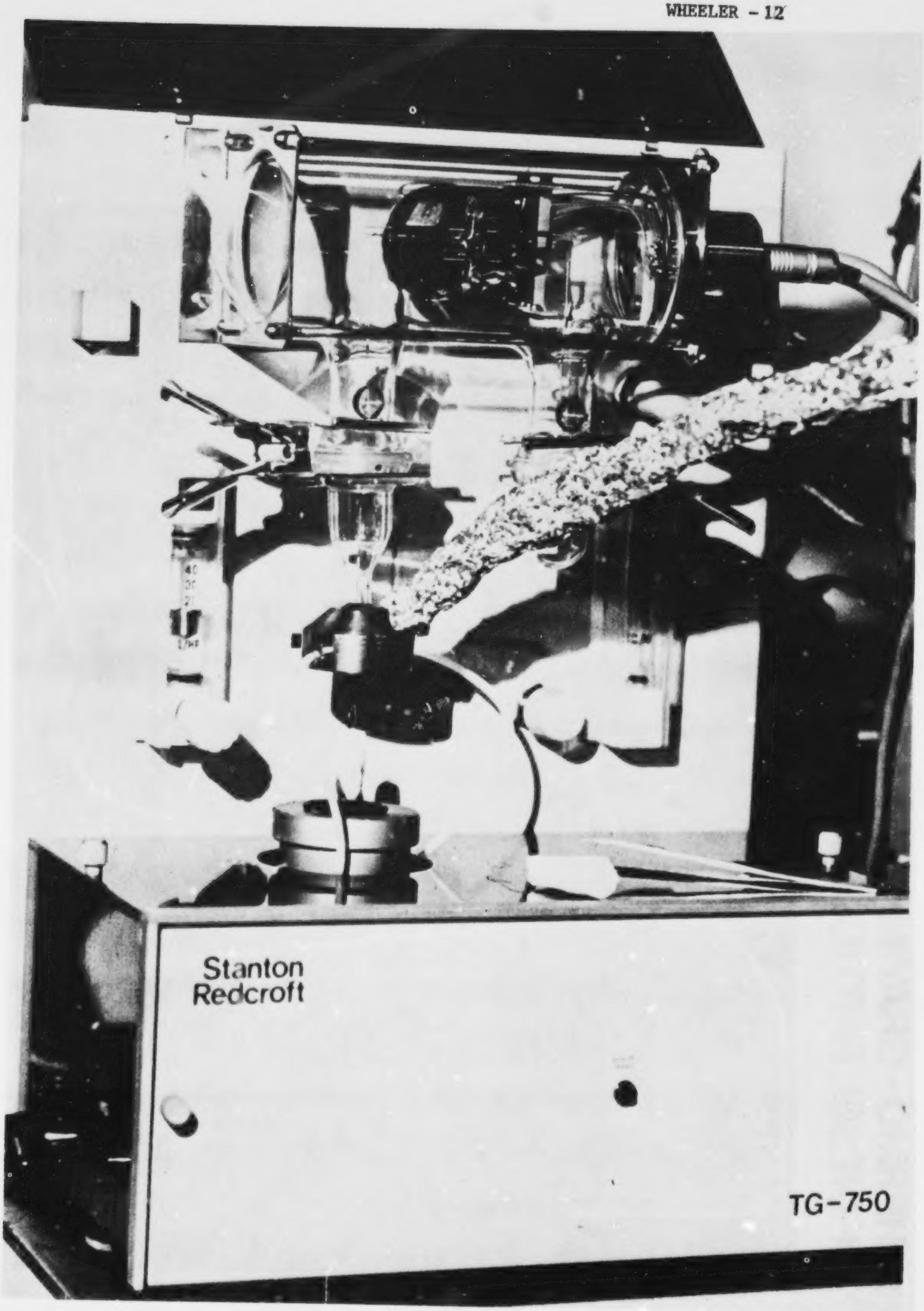
by the use of solvents, solvent extraction, are not fine research methods; but I shudder to think of diesel engineers having to do this as a regulatory procedure or even as a developmental procedure. So, we have devised a procedure which, undoubtedly, can be criticized possibly for altering the hydrocarbons but, certainly, would be adaptable to use in an ordinary diesel manufacturing plant.

What we are using is a thermogravimetric analyzer, Figure 12, a fairly traditional instrument. It is just a sensitive balance. The filter paper which we have taken from the filter holder, is rolled up, and is hanging from the beam. The furnace is then lifted around it, and you program the temperature in the furnace to a certain rate of rise which we have not yet fully determined; and the hydrocarbons which come off are taken through the heated line to an FID so the hydrocarbons can be looked at. They could be taken to a GC or mass spec, but at the moment we are really only considering totalizing them by standard heated FID; and at the same time as we are doing this heating process and boiling these hydrocarbons off, we are weighing them automatically on the same chart. So, we have an automatic weight record of the evaporation of the hydrocarbons against the temperature; and finally, we get the plateau where the hydrocarbons have all come off. This all is done while passing nitrogen through the whole system.

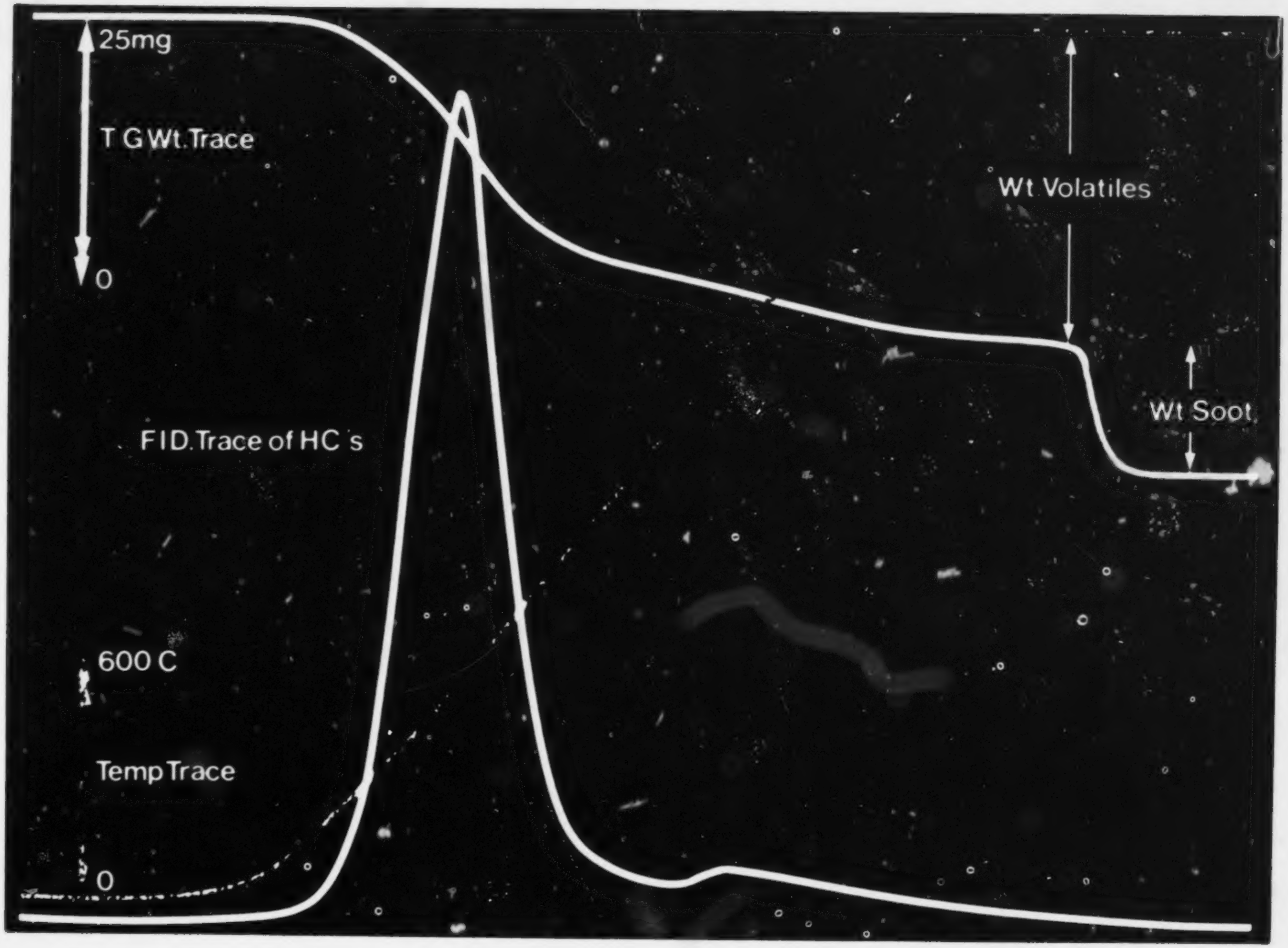
We then switch to air and oxidize the soot. So, we get the weight of the soot and the weight of the hydrocarbons. It is just possible that this could be the germ of a future regulatory procedure.

The curves shown in Figure 13 are from just a smoothed out typical chart. The temperature, weight loss, and FID hydrocarbon traces are self explanatory, with a clear demonstration of the plateaus when the hydrocarbons are evaporated and the soot oxidized.

This is actually from a specific paper, from a total FTP, from a diesel car. The curves show quite a large amount of hydrocarbons compared with the actual amount of soot due to the engine having defective injectors.


Stanton
Redcroft
TG-750

THERMO-GRAVIMETRIC ANALYSIS OF DIESEL PARTICULATES



RICARDO

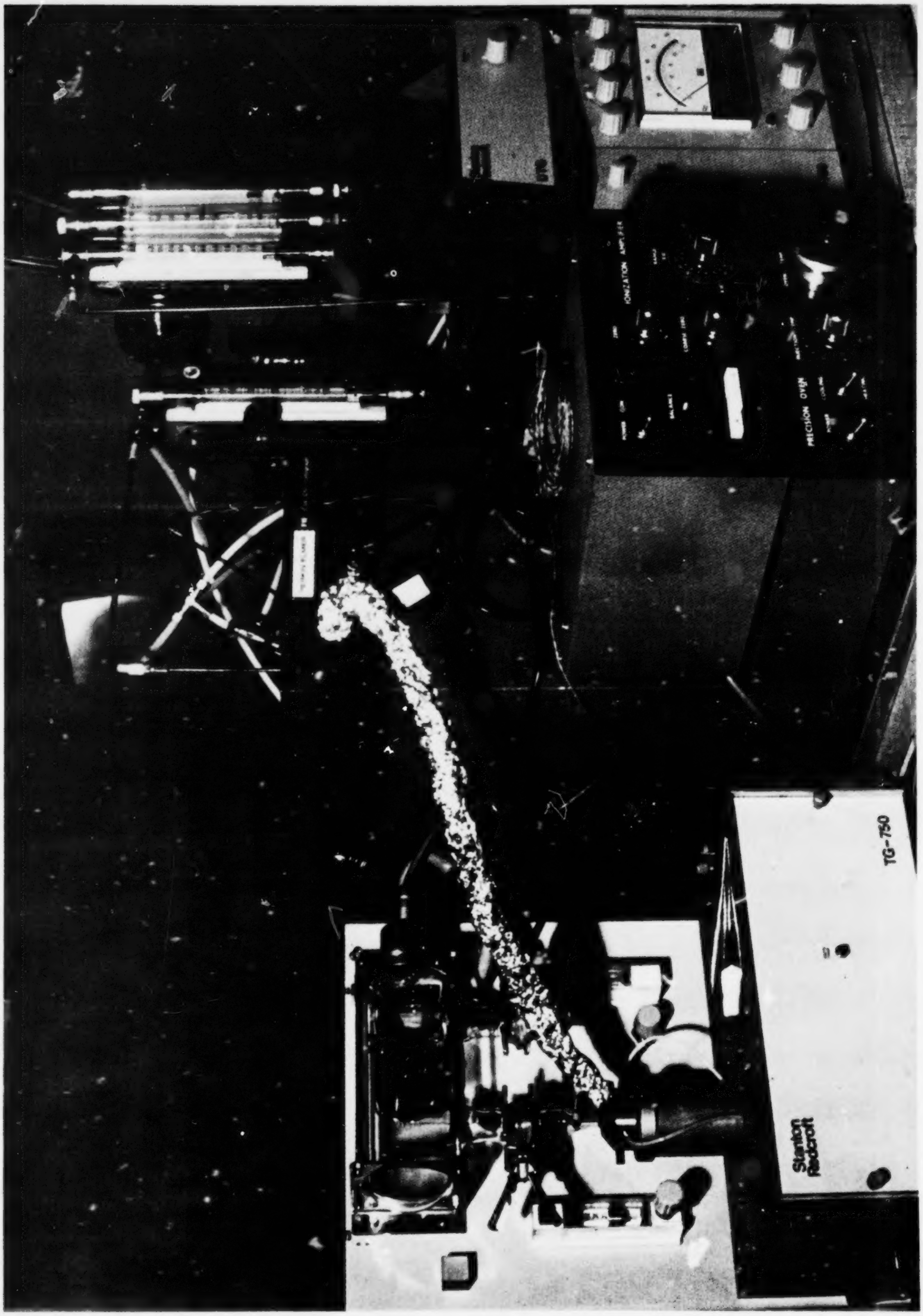
It is a very simple developmental procedure which could be used in any engine laboratory.

The whole equipment is shown in Figure 14. There is a Perkin-Elmer GC, an old F11 which has been converted into a totalizing hydrocarbon analyzer connected up to a Stanton Redcroft TGA. Some considerable amount of work needs doing to optimize a TGA to take the paper from a test.

So, that is the sort of way that we are looking at these samples; and so, that is the method we are using now on a straightforward engine developmental basis to optimize diesel engines for low particulates and to have some knowledge of where the hydrocarbons are going. The work is in fairly early stages, and it is hoped possibly to report it early next year.

Thank you, gentlemen.

PROF. JOHNSON: To continue then, we are down to "Diesel Emissions Measurements of Heavy and Light-Duty Vehicles" on the program, and our speaker is David W. Turner of Exxon.


IONIZATION AMPLIFIER
PRECISION OVEN
TG-750
Stanton Redcroft

MR. TURNER: Our program on measurement of diesel emissions is essentially broken up into two phases. One is on heavy duty engines, and the other one is on light duty engines. You will note that there are similar objectives under each, the typical gaseous emissions, opacity and fuel performance.

In the light duty program, the PNA's are not being studied. I have underlined the things I will discuss today. In the heavy duty program, the opacity measurement and the PNA's; in the light duty program, particulates.

The first thing that I would like to discuss is our PNA work, and on the next vugraph (2), I show our sampling setup for sampling PNA's from an engine. It is an isokinetic sampler. You pull a sample from the exhaust through a precooler into some bubblers and through a filter. It is pretty typical for isokinetic sampling.

We did sample from two points, point one and point two shown in the vugraph.

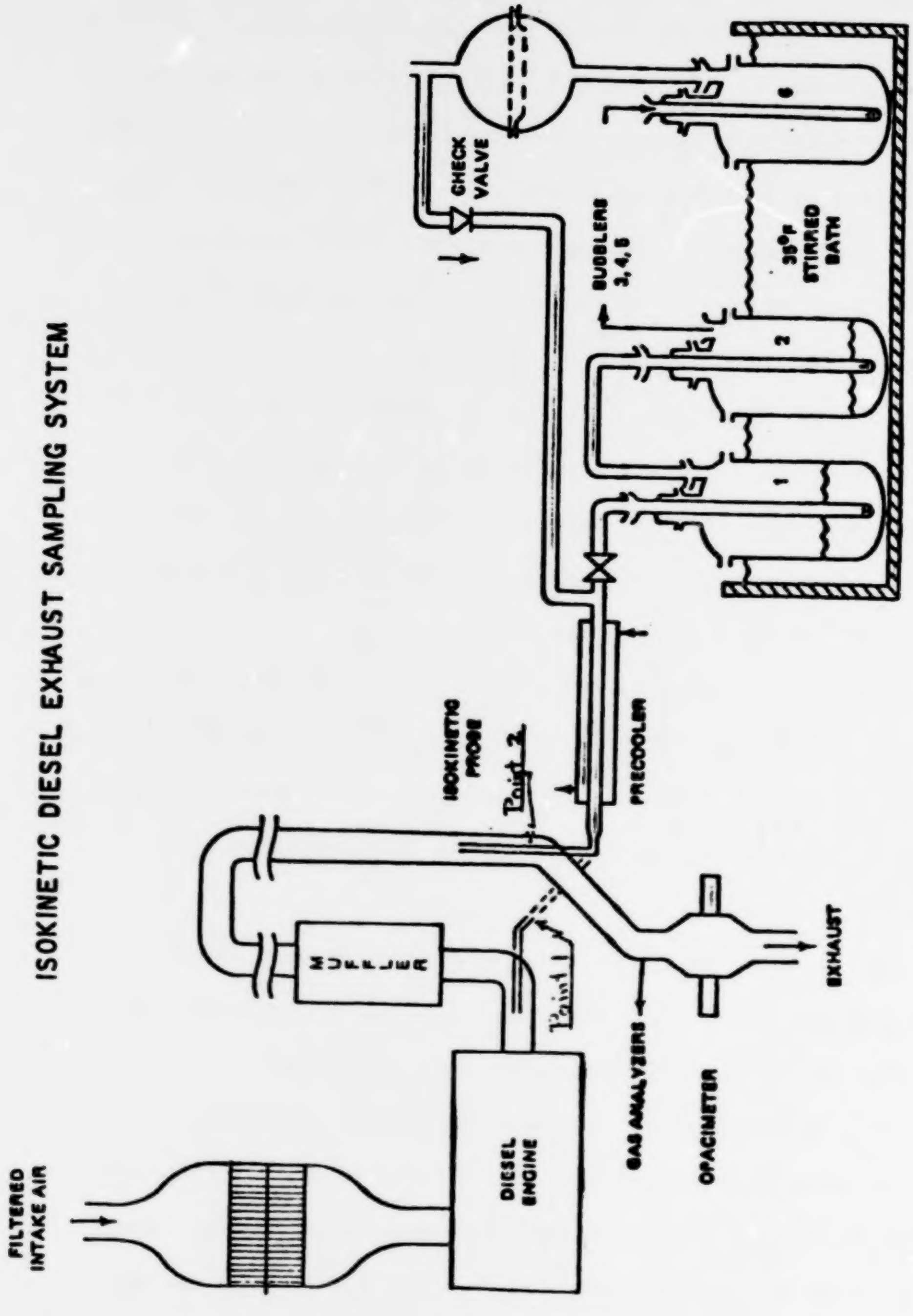
Between these two points (at full load), the gases have about 60 milliseconds of residence time and at the engine conditions we chose, the temperature was about 975 degrees Fahrenheit.

Now, everybody knows the hardship that is involved in measuring PNA's, both from the sampling side, and from the analytical side, and Mr. Heuss discussed those in some detail earlier.

Our analytical determination of PNA's was by the GCUV method in which you extract the soot and the bubbler samples, go through several separation stages and finally end up doing a GCUV analysis, GC for trapping, UV for counting. We do use a radio tracer technique, as well.

MEASUREMENT OF DIESEL EMISSIONS

- HEAVY DUTY DIESEL ENGINES
  - NO_x, CO, HC
  - OPACITY
  - PNA'S
  - FUEL PERFORMANCE
- LIGHT DUTY DIESEL ENGINES
  - NO_x, CO, HC
  - PARTICULATES
  - FUEL PERFORMANCE



ISOKINETIC DIESEL EXHAUST SAMPLING SYSTEM

On the next vugraph (3) are some of the data that we obtained at Point 1 and Point 2. First of all, you will find on the left of the vugraph, we have all the PNA's that are typically measured, 10 of them.

As you go from Point 1 to Point 2, you will note that there is a significant reduction in the amount of PNA's that are sampled, and we have simply calculated the difference as a percent survival in the third column. We find that about 50 percent are actually reacting as they travel between these two points in the exhaust system.

As you look down the specific species of PNA's that we did measure, you will find that the percent survival is, in general, lowest for the most reactive specie and is highest for the most non-reactive specie. It is just what you would expect.

Now, this could have been an artifact of our sampling system or our analytical system. So what we did was to take a sample of known PNA content and actually inject this sample into the exhaust system at Point 1, and on the next vugraph (4), I have the results of that experiment.

The first column is what we would have expected to measure as an increment over and above what the engine was putting out, and the second column is the percent change from that increment.

Now, in the previous vugraph, the average survival was 52 percent. In this vugraph, you will see it is 64 percent. I believe the difference between the two results is experimental error. Again, if you look down the species themselves, you will find that the most reactive has the lowest survival rate, and the least reactive has the highest survival rate.

DIESEL EXHAUST PNA ARE OXIDIZED IN THE EXHAUST SYSTEM

	SAMPLE TAKEN AT POINT 1, µG	SAMPLE TAKEN AT POINT 2, µG	% SURVIVAL, AS $MEAN_2/MEAN_1$
	MEAN	MEAN	
PYRENE	42.9	23.8	55.5%
FLUORANTHENE	31.7	24.4	77.0
BENZ(A)ANTHRACENE	4.97	1.70	34.1
CHRYSENE	13.6	6.40	47.2
TRIPHENYLENE	12.9	6.50	50.6
BENZO(A)PYRENE	6.94	2.59	37.4
BENZO(E)PYRENE	6.16	1.89	30.6
BENZO(GHI)PERYLENE	1.09	0.59	54.1
MeBENZO(A)PYRENE	0.94	0.54	57.3
MeBENZO(E)PYRENE	1.08	0.87	80.8
		AVERAGE SURVIVAL =	52.5%

INJECTED PNA ARE ALSO OXIDIZED IN THE DIESEL EXHAUST SYSTEM

	EXPECTED SAMPLE INCREMENT FROM INJECTION OF PNA	MEASURED INCREMENT AT POINT 2 G. MEAN %
PYRENE	61.7	72.2
FLUORANTHENE	48.2	72.0
BENZ(A)ANTHRACENE	15.8	39.7
CHRYSENE	21.5	48.7
TRIPHENYLENE	2.82	105.6
BENZO(A)PYRENE	24.4	32.9
BENZO(E)PYRENE	17.7	140.9
BENZO(GHI)PERYLENE	25.7	23.8
MeBENZO(A)PYRENE	12.7	21.5
MeBENAO(E)PYRENE	11.9	86.8
	AVERAGE SURVIVAL =	64.4%

In other words, it does make a difference where you sample in the exhaust system. They are reactive. They do go somewhere. We spent considerable effort in removing background material for our GCUV PNA analysis, and now we are faced with the possibility of going back to get the background material for identification.

As I said before, our primary emphasis in all of this work is to look at fuel effects, and part of our heavy duty effort at the present time is to look at a number of fuels in respect to gaseous emissions and smoke opacity as well as the performance of the fuels themselves.

In the heavy duty program, (the next vugraph, 5), we have blended a fuel set that consists of 14 fuels. In this vugraph, I show the ranges of fuel inspections in the fuel set.

As you can see, there is quite a wide range in 10, 50 and 90 percent points and API gravity. Aromatics are going from 10 percent which is well below what you would get commercially to essentially 60 percent which is well above what you would ever expect. Viscosity in general brackets the entire range that you would expect, and cetane number goes well below existing specifications anywhere.

In all of this work, we are looking to determine exactly what makes a fuel work well in an engine. We are looking at power output, specific fuel consumption, and emissions. To give you an idea of the data in terms of smoke opacity, on the next vugraph I have plotted up the results of our tests on smoke emissions.

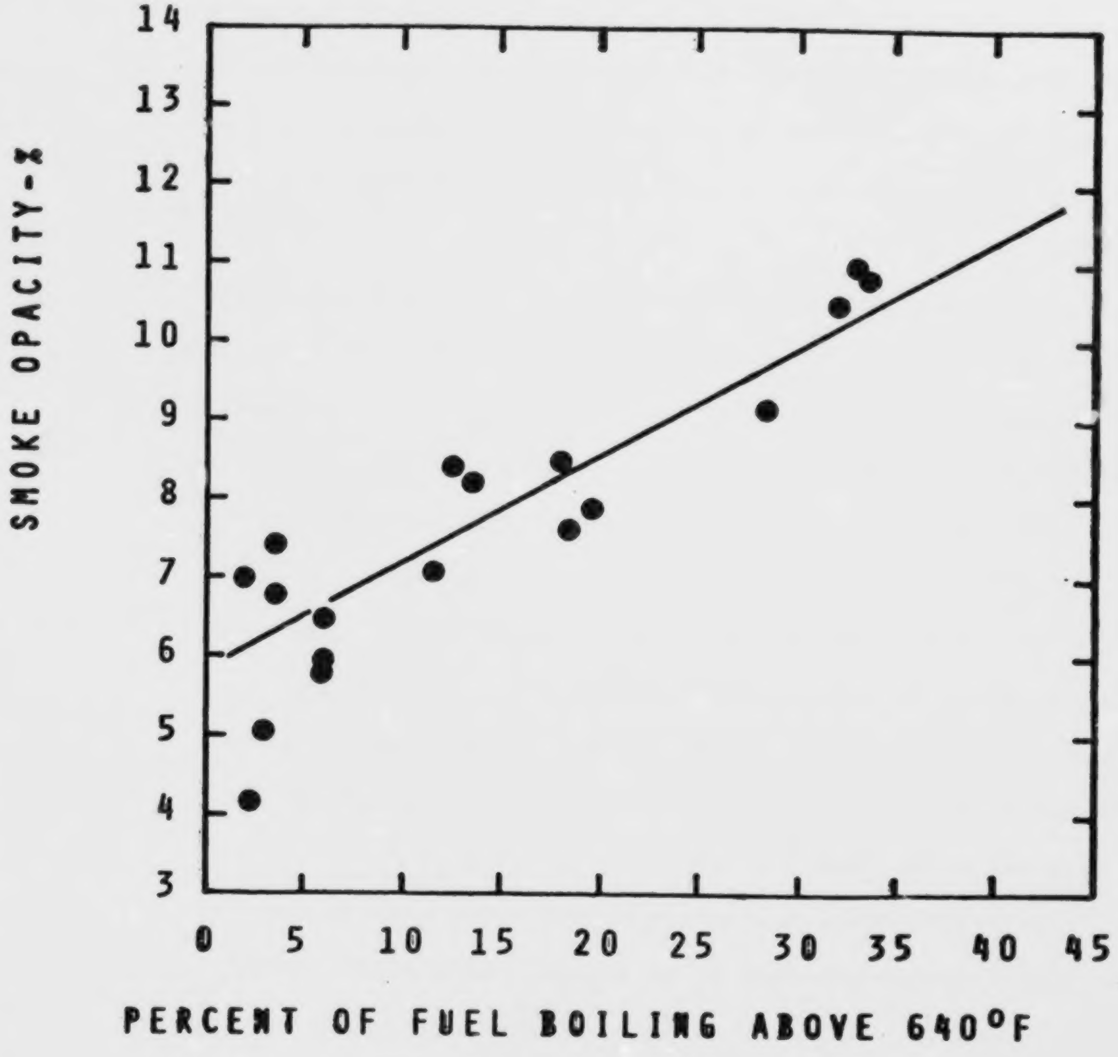
The ordinate on this vugraph (6) is the smoke opacity which is the average opacity for four different RPM's at full load.

The smoke opacity is plotted against the percent of fuel boiling above 640°F. This has turned out to be the best correlating

FUEL SET DESIGN

14 FUELS (INCLUDING REFERENCE FUEL)

INSPECTION	RANGE		REFERENCE FUEL
	MIN	MAX	
DISTILLATION			
10%	385	520	425
50%	452	613	491
90%	574	692	582
API GRAVITY	22.7	43.6	35.5
AROMATICS %	9.7	57.7	33.5
VISCOSITY CST @ 100°F	2.21	6.95	2.64
CETANE NUMBER	28.9	52.2	45.9



VARIATION OF SMOKE OPACITY
WITH FUEL VOLATILITY

AVERAGE OPACITY FOR 1350, 1600, 1850 & 2100 RPM
FULL LOAD

variable we could find to date. With our ranges in distillation characteristics, there is a good chance that we are getting droplet residues, as well as other hydrocarbons coming out of the engine. One of the problems with the opacity measurement is that it does measure anything that blocks or scatters light, not just smoke.

Now, on the light duty side, we are measuring particulate weights from vehicles. I don't have a vugraph on this data, but we have baseline particulate levels for three vehicles, and we see that there is a difference between the Gellman and the Pallflex filters, as reported by EPA. There was a problem with hydrocarbon adsorption on the Gellman filters.

Our preliminary results indicate that there is a surprisingly consistent or a constant value of particulates when you make it relative fuel consumed. In other words, if you express your particulate measurements relative to a gallon of fuel, i.e., grams per gallon, it does not seem to matter what vehicle you are testing in terms of particulate level. It all seems to come out to be the same regardless.

On the last vugraph (7), I have attempted to just list some of the things that we are interested in doing in present and future programs. Some of the items we have already done to a certain extent for the particulate emissions program. The characterization, we have done in terms of the PNA's, but there are other things that need to be done. Some of the results that are being seen today could be a direct result of the actions occurring in the exhaust system itself rather than in the cylinder. Engine effects, time/temperature history of exhaust gases, injector design, and improved mixing all have a chance of helping out the situation.

PROGRAM DEVELOPMENT

PARTICULATE EMISSIONS

- CHARACTERIZATION
- WHERE FORMED
- ENGINE EFFECTS
  - INJECTION DESIGN
  - TIME/TEMPERATURE HISTORY OF EXHAUST
  - IMPROVED MIXING IN CYLINDER
- FUEL EFFECTS
  - COMPOSITION
  - VOLATILITY
  - ADDITIVE REQUIREMENTS (COMBUSTION/ATOMIZATION ETC.)
- POST ENGINE CONTROL

From my viewpoint anyway, fuel effects have to be examined as well. We are looking at composition, volatility, and also additives. There is a chance that additives could help us in reducing particulate matter in the exhaust and post-engine control should be looked at in terms of cleaning up the exhaust gases.

(Applause.)

PROF. JOHNSON: Thank you, David.

The next talk that we have on the program is the Development of a Recommended Practice for the Measurement of Particulate Emissions from Light Duty Diesel Engines by Merril Korth of EPA.

Merril has the job of synthesizing all this research and practical engineering that Dick Wheeler has talked about.

MR. KORTH: Thank you and good morning. I am sure that all of you by now know that the amendments that were made to the Clean Air Act last August said that somebody had to come up with regulations for diesel particulates.

As it turns out, that somebody happens to be the Standards Development and Support Branch of the Environmental Protection Agency located in Ann Arbor, Michigan.

The main thing I want to talk to you about this morning is the status of the regulation development process in the area of the light duty diesel and the light duty diesel truck and, more specifically, point out some of the measurement techniques that are being considered.

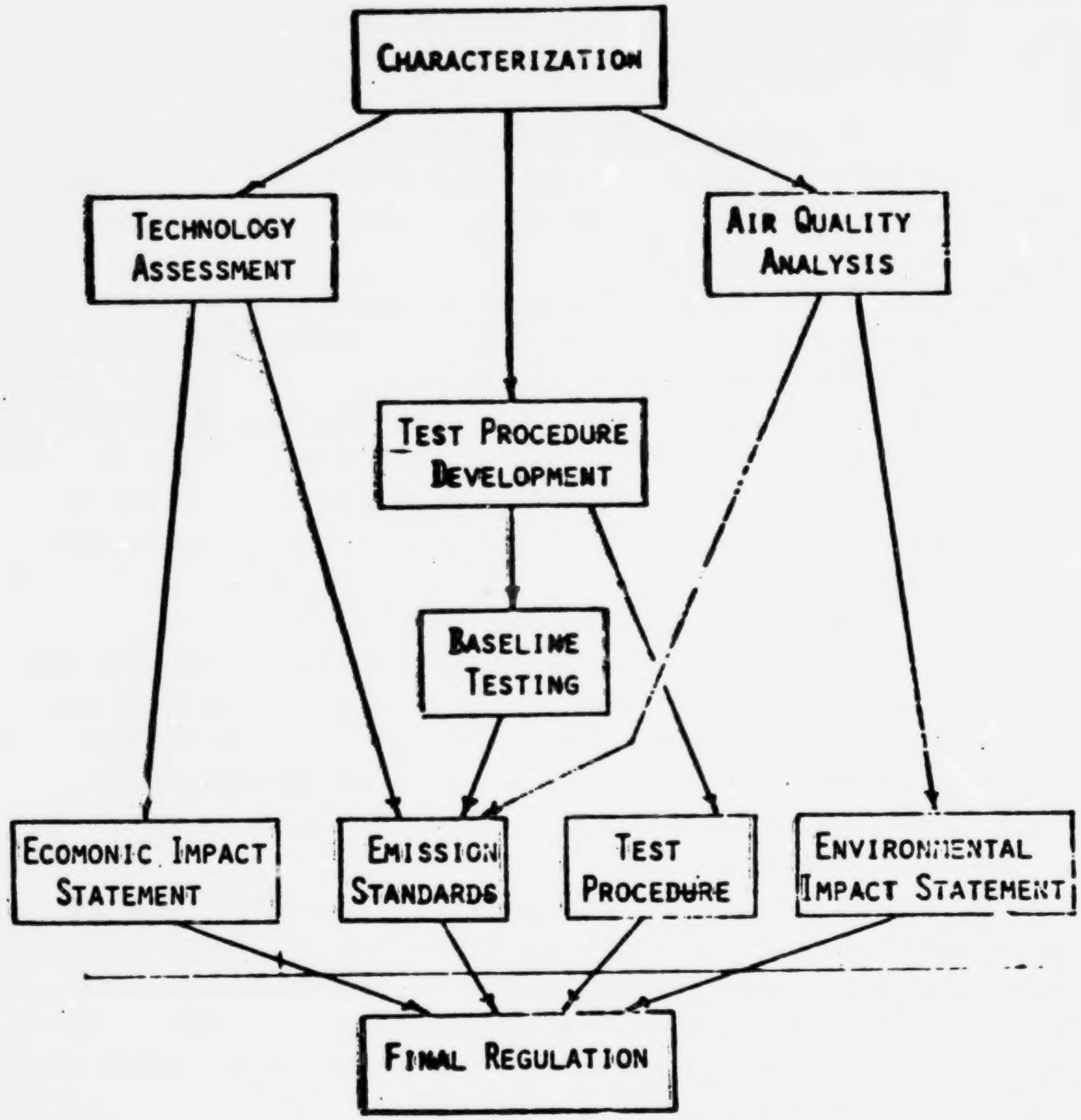
Could we have the first chart, please? #1

This is a diagram of the general regulation development process that we go through on any new area to be controlled. In this case, there is characterization information that has come both from EPA studies and also information from industry sources which provide background information for the technology assessment and the air quality analysis.

Of course, at the beginning of any new regulation you have to decide how you are going to measure the pollutant. That process is moving. A recommended practice or draft recommended practice has been completed and distributed during the last part of March, soliciting comments from anyone that has information or an interest in this area.

As soon as you have a test procedure, you can begin to gather baseline information on existing vehicles. As far as the status of

REGULATORY FLOW CHART



our progress at this point, we are well along in both the technology assessment and the air quality analysis.

As I said, the recommended practice for the test procedure has been distributed, and we have quite a range of tests completed for baseline information on existing vehicles, both for light duty vehicles (cars), and several light duty trucks.

We are working towards the finalization of the rest of the regulations which is scheduled to be published in the Federal Register before the end of this calendar year. We hope to have completed the draft in Ann Arbor by the end of June.

Next chart? #2

Again, this is not new information. It is very conventional measurement technique. Our philosophy has been to stick closely to what we feel we know best and the experience that we have gained in measuring sulfate particulates and lead particulates.

This chart is a representation of a CVS with essentially the insertion of a dilution tunnel. It is a positive displacement CVS and filter box, with the sample entered through a mixing orifice about 10 diameters from where we take a sample of the particulate for analysis.

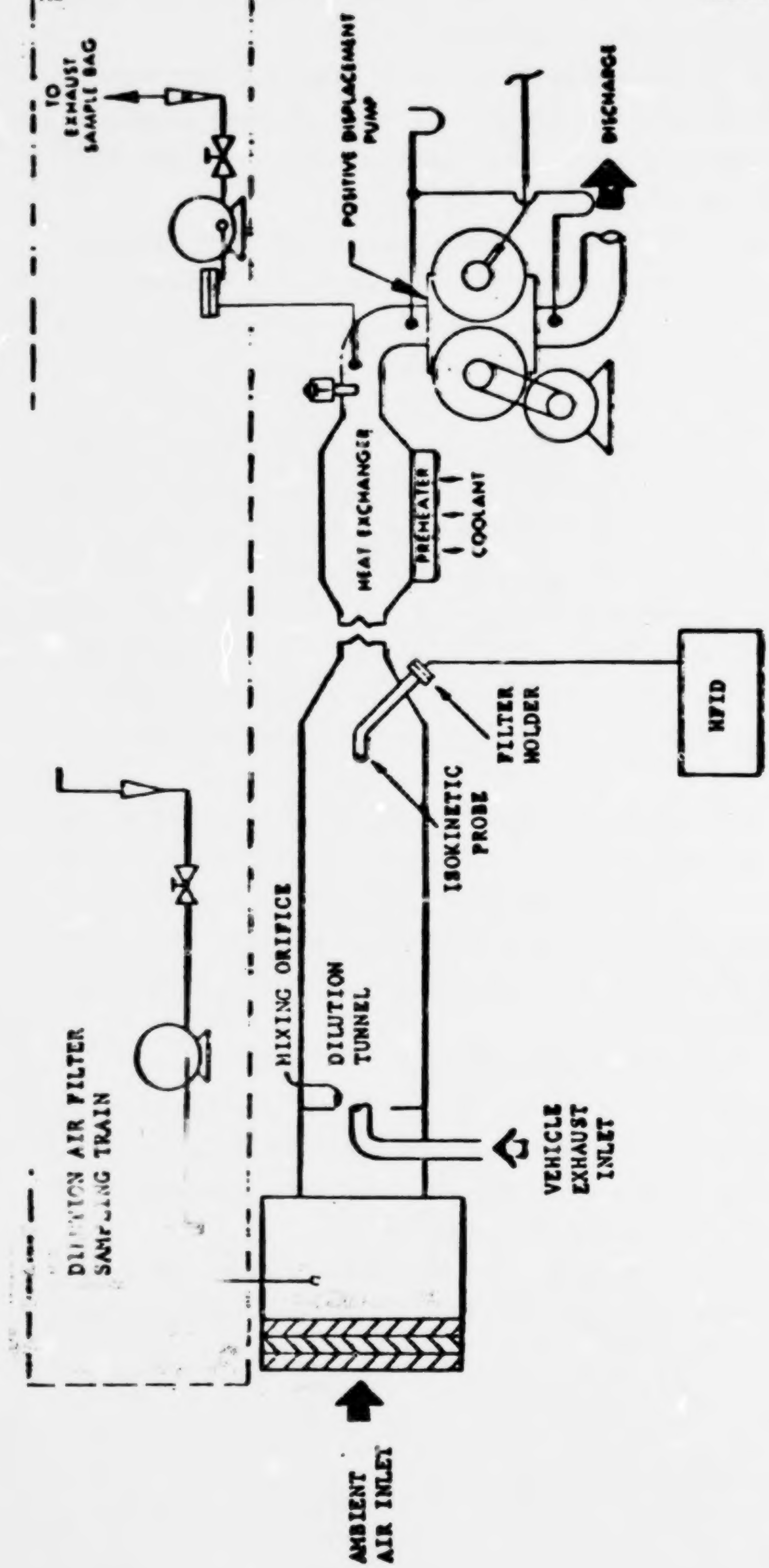
The flow rate in our recommended practice is specified by the temperature at the sample point which, as Mr. Wheeler mentioned, is commonly spoken of as 125 degrees Fahrenheit. This dictates what the dilution ratio has to be for a given sized vehicle.

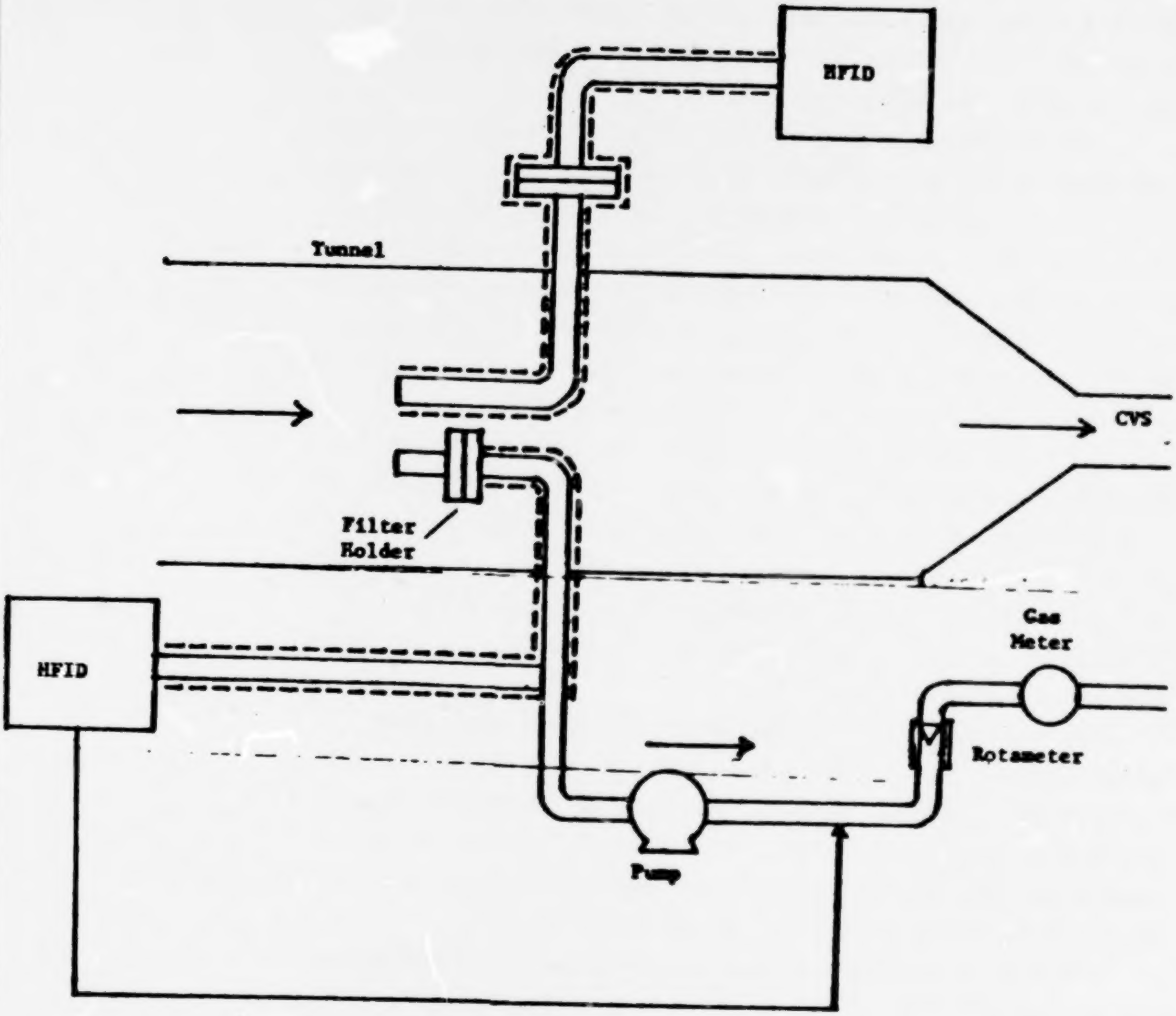
The diameter of the tunnel that we are using in our baseline test is 18 inches.

Could we have the next slide, please? #3

This chart deals more specifically with the sampling technique. We are not sure how important isokinetic sampling is to diesel particulates, since it is very fine and very lightweight. So, that parameter is not specified very closely.

The sample is collected on a 47 millimeter filter. We are using Pallflex, which is a Teflon coated fiberglass, (not a Teflon


TO EXHAUST SAMPLE BAG
POSITIVE DISPLACEMENT PUMP
DISCHARGE
HEAT EXCHANGER
PREHEATER
COOLANT
FILTER HOLDER
HFID
ISOKINETIC PROBE
MIXING ORIFICE
DILUTION TUNNEL
VEHICLE EXHAUST INLET
DILUTION AIR FILTER SAMPLING TRAIN
AMBIENT AIR INLET



Particulate Sampling System

filter, but a Teflon coated fiberglass filter), and a conventional pump and volume measuring system. The filter is operated at tunnel temperature. There is no heat applied to the system until after the filter.

To get an idea of the amount of organic material connected with the particulate sample, we are measuring the hydrocarbon after the cold filter and, also, the total hydrocarbon through another completely heated system in a similar manner to what is done now in the regulation for diesel hydrocarbons.

The difference between the two hydrocarbon measurements is an indication of the total organics associated with the particulates.

The test cycle that is being used is the LA4. There is no change considered in that area. The present regulated gaseous pollutants are measured at the same time as the diesel particulate.

Particulates and hydrocarbons are measured in the dilution tunnel. The normal regulated pollutants, CO, hydrocarbon, oxides of nitrogen, are measured in the CVS bag, as we do now.

As I said before, we have selected the more conventional measurement techniques as far as sizing the CVS and the tunnel and the hardware involved. This means that for larger diesel cars, the 300 to 350 CFM CVS units that are normally used are somewhat small to maintain the 125 degree temperature at the sample point; and it requires an increase of up to 60 percent in that flow to get the desired temperature.

In putting out the recommended practice, we hope to get comments on all issues; and also, hopefully, data which will help us to better understand how important some of the design parameters are to the measurement system. If we have sufficient information to support modification of the sample system, this could be done before the notice comes out before the end of the year.

We would appreciate any comments or ideas on the subject that can be offered.

Thank you very much.

PROF. JOHNSON: Thank you, Merrill.

We are down to our last paper which is called "The Summary of Characterization Work on Light and Heavy Duty Diesels," by Dr. Joe Somers of EPA.

Joe?

DR. SOMERS: Thank you, John.

EPA has been doing diesel characterization work for the past several years now. The work is done jointly by the Office of Mobile Source Air Pollution Control in Ann Arbor, Michigan, and the Office of Research and Development in RTP. That is Ron Braddow who is helping us do some of the work.

Most of the work we have done on diesel particulates has been under contract, supplemented by some in-house work. The contracts we have had over the past several years have been with Southwest Research Institute under the direction of Karl Springer.

In this work we have looked at both heavy duty diesel engines, as well as light duty diesel vehicles. Today, I would like to go over very briefly some of the things that we have learned and discuss some of the work that is in progress add, then, conclude by stating what some of our futurepplans are.

The discussion today will be only an overview. We intend to present some of this information in a lot more detail next month. On May 17, EPA, ORD, as well as the Office of Mobile Sources, is planning a joint diesel particulate characterization seminar in Ann Arbor, Michigan; and that will be a day and one-half, and, in effect, cover a lot of the material I am going to be going over this morning.

On the heavy duty area, the characterization work on particulates was done using the exhaust splitter, which several speakers have already mentioned this morning, so that a small fraction of the exhaust flow was diverted into a dilution tunnel.

A number of engines have been characterized and a number of different fuels. The cycles used to measure the particulates are generally the 13 mode cycle which consists of a collection of steady-state conditions. Both two-stroke cycle and four-stroke cycle engines have been used in the work. On the two-stroke cycle, which is characteristic of bus engines, we used the Detroit diesel 6L71T, as well as the 6V71.

Here these engines were run on a number of different fuels, diesel fuel number one and number two, as well as a fuel that was designed to be intermediate between the two. They were, also, tested with a number of different additives, and the overall emission rate we found from the two-stroke engines is about 4.7 grams of particulate per kilogram of fuel.

We measured mostly just the total particulate mass; but in addition, especially over the past year, some work has been done to look at the organic fraction of the particulate. For the two-stroke cycle engine, there is much variability in the organic fraction. It is generally fairly high, and we found numbers up to about 70 percent or so.

For the four-stroke cycle engine, we have also characterized a number of engines. The engines of interest are the Cummins 855 TC, Caterpillar 3208 on which an awful lot of work has been done, and the Mack ETAYB673A.

For the four-stroke cycle engine, the particulate emission rate has been much lower than for the city bus type two-stroke cycle engine. Very approximately, the emission rate we found here is about 2.6 grams of particulate per kilogram of fuel. So that is 50 percent of what we found for the two-stroke cycle.

It is very easy on these engines when we do the 13 mode test with an engine dyno to collect the emissions in just that fashion, grams per kilogram of fuel. It is much more difficult to convert those numbers into grams per kilometer distance traveled.

To do that conversion, we have to make an estimate of the fuel consumed over a certain distance; and this depends to a very large extent over the duty cycle of the engine. We have done some work making this conversion. To do this, we have looked at some average speeds that have been characteristic of these engines. This was done through the Coordinating Research Council CAPE 21 Project; and in this project, a number of diesel buses and trucks were outfitted in both the New York City and LA area to characterize their operation. Things such as speed, distance, as well as fuel consumption were monitored.

From this work, we got an idea of what the average speed would be for these heavy duty diesels, and there is quite a variability from 13 kilometers per hour up to about 50 as the average speed. Buses are, of course, much lower. For the LA area, the average speed for the trucks was 50 kilometers per hour, for buses 32; for the New York area, 21 kilometers per hour for the trucks and 13 for the buses.

Previous work at Southwest measured fuel consumption over a number of different cycles which we were able to relate to these speeds. From the speeds as well as the fuel consumption work done at Southwest over a number of different cycles and steady-state spee speeds, we converted the particulate numbers I just gave you to distance numbers, that is, grams per kilometers which can be used in air quality models.

What we found here for the buses was an emission rate of approximately 2 grams per kilometer for particulate mass, and for the four-stroke cycle trucks, a particulate emission rate of about 1.3 grams per kilometer. Both of these rates are, of course, much higher than that for light duty diesels which have been covered in several of the previous discussions this morning. We have also done a lot of work here as well; and it is clear, obviously, that a lot more work is needed in the heavy duty area.

We have, also, done a number of comparisons on the heavy duty engines, looking at the effect of different engine parameters on the particulate emissions as well as comparing the heavy duty diesel engines to some gasoline counterparts.

Some work here was recently completed at Southwest where a Caterpillar 3208 engine was tested. Here, the particulate rate was about 10 grams per kilogram of fuel particulate mass. FFor a comparable GM366 heavy duty gasoline engine, the particulate rate was about .6 grams per kilogram of fuel. So, there is about a 15-fold difference between the two. For the GM366 gasoline engine leaded fuel was used, which was responsible for most of the particulates. Work is presently ongoing to measure the effect of various parameters on these emissions. Things such as injection timing, the presence of EGR, turbo-charging or lack of it, different injection systems, and so on, are being tested on some of these engines.

This work is in progress; and for now, we don't have any results. However, this work, which will be completed in the next several months, will give us a very good idea of what these various parameters do for particulate emissions; and, thus, they will give the agency a very good idea of available, in effect, control technology. In other words, how does varying one of these parameters affect particulate emissions, versus regulated gaseous emissions?

In addition to the heavy duty diesel work, a number of light duty diesels have been tested. We have done quite a variety of work there. I had some slides from an earlier talk, which I was able to pull together this morning; and the first slide sort of gives an overview of some of the diesel work in the light duty area. #1

In the light duty diesel work, we measured a number of other emissions other than just particulates. This slide contains a list of some of the emissions that we measured. It is probably not very visible from the back of the room. These emissions were measured for both the heavy duty engines and the light duty diesels.

In light duty diesels, we tested the VW Rabbit to a very large extent. We have also tested an early prototype of the Olds diesel. This work was done about a year ago and was presented in some detail at the September SAE meeting.

The slide lists some of the other emissions that were measured, BaP, sulfates, odor, noise; aldehydes were measured and the regulated gaseous emissions.

Characterization of Sulfates, Odor, Smoke, POM and Particulate from LD and HD Engines

I. Heavy Duty Engine Testing
(testing not completed)

II. Light Duty Vehicle Testing
- A.) Vehicle Selection
  - 1.) VW Rabbit Diesel
  - 2.) Oldsmobile Cutlass Diesel
- B.) Emission Testing
  - 1.) Gaseous Emissions During Urban Driving Cycles
    -HC, CO, NOx, fuel consumption, aldehydes
  - 2.) Smoke
  - 3.) Particulate and Sulfate
  - 4.) BaP
  - 5.) Odor
  - 6.) Noise

The next slide gives a listing of some of the fuels that were used in some of these tests. Part of this work covered an investigation of how various fuels affected light duty diesel particulate emissions. The five fuels that were tested in this work are listed in the first part of the slide and included the conventional diesel number two test fuel that is used now in emission tests, as well as a national average test fuel, in effect, a fuel that is a composite of what is representative across the nation as a whole. A jet A was used, a minimum quality diesel fuel that is relatively high in aromatics, and low in cetane was used; and then a premium diesel test fuel that was low in aromatics and high in cetane. #2

Most of the work has been done with a conventional test fuel, the first fuel listed. We don't yet have the results for the other four fuels complete. However, there does seem to be a very large effect of the fuel itself on the emissions. We find that the soluble organic rate, as well as the total particulate mass, is greatly affected by the type of fuel used, a much larger effect than we initially though would be the case.

The fuel work in specific looked at the VW Rabbit, which I mentioned earlier, as well as the Mercedes 240D. For the Olds diesel which we tested, we just used the first fuel, the number two test fuel. The emissions that were measured in all of this were as before and are listed in the end part of the slide.

If I could have the next slide? The work that is done so far on which we have results are the VW Rabbit and the Olds diesel. #3

The next slide gives some of the gaseous emission results for the VW diesel. We measured the HC, CO, and NOx over a variety of different driving cycles. The first line is the 1975 federal test procedure which is used for the emissions standards. The next three cycles are various variations of that, the cold start FTP, the hot start FTP, and what we have on the last part is the sulfate emission test, a driving cycle that has a slightly higher average speed than the federal test procedure and no cold start.

Emission Characterization of LDD with Various Fuels

I. Fuel Selection
- A.) 2-D Emissions Test Fuel
- B.) No. 2 "National Average" Fuel
- C.) Jet A Fuel
- D.) No. 2 Minimum Quality Fuel (High Aromatic)
- E.) No. 2 Premium Fuel (High Paraffin)

II. Test Vehicles
- A.) VW Rabbit Diesel
- B.) Mercedes 240 D

III. Sampling and Analysis Procedures
- A.) Smoke
- B.) Odor
- C.) Particulate
  - -total mass, size distribution, $SO_4^=$, S, C, H, N phenols, organic extractables, BaP, MW range
- D.) Gases
  - -HC, CO, CO_2, NOx, aldehydes, specific hydrocarbons

Average HC, CO, NOx for VW Rabbit

		Emission Rate, g/mi		
Cycle	Vehicle	HC	CO	NOx
'75 FTP	D	0.37	0.79	0.87
	G	0.23	3.70	1.01
FTP Cold	D	0.61	0.92	0.87
	G	0.30	4.62	1.08
FTP Hot	D	0.21	0.71	0.89
	G	0.19	3.12	0.96
SET	D	0.15	0.55	0.81
	G	0.05	0.30	1.62

From these numbers, which were given in the SAE paper last September, you can see that the VW had slightly higher hydrocarbons for the diesel version than for the gasoline. The CO, on the other hand, was somewhat lower for the diesel; and the nitrogen oxides were very approximately the same.

#4 The next slide gives the same results for the Olds diesel. As I mentioned previously, the Olds diesel testing was an early prototype. Since then, Oldsmobile has made some changes to the diesel; and these changes affect both the particulate emission numbers and the hydrocarbon, both of which are lower than they were when we ran the test.

Here, the hydrocarbons from this particular version are relatively high for the diesel one and much lower for the gasoline version which was the 260 CID displacement engine.

The CO is more or less about the same for both cycles, maybe a little lower for the diesel; and the nitrogen oxides are about the same.

#5 The next slide gives some of the particulate numbers. The Olds diesel had an extremely high particulate number, almost a gram per mile. The VW Rabbit, on the other hand, was very much lower than the diesel version, about .3 grams per mile for the federal test procedure. As expected, the gasoline version of both cars was much, much lower in particulates.

The characteristic of the particulates is, of course, entirely different. For the gasoline version, the particulates consist mostly of small quantities of sulfuric acid; whereas, for the diesel, there were high quantities of elemental carbon as well as organic matter. About 20 percent of the particulate mass for these cars was organic matter.

#6 The next slide gives a rough comparison of the particulate emissions from these cars versus a number of other kinds of cars. You can see that the VW Rabbit and Olds diesel are relatively far off from the average we found from testing about 20 or so light duty dic

Average HC, CO, NOx for Olds Cutlass

Cycle	Vehicle	HC	CO	NOx
		Emission Rate, g/mi		
'75	350 D	0.76	2.00	1.13
	260 G	0.39	2.16	1.37
FTP Cold	D	0.95	2.20	1.37
	G	0.63	3.78	1.64
FTP Hot	D	0.58	1.80	1.11
	G	0.22	0.88	1.09
SET	D	0.43	1.27	0.95
	G	0.13	0.85	1.38

Particulate Rate Comparison mg/mi

	Cutlass		Rabbit	
Cycle	Diesel	Gasoline	Diesel	Gasoline
'75 FTP	922	9.06	293	6.18
FTP Cold	1010	13.48	325	7.96
FTP Hot	842	5.71	265	4.84
Set	579	15.64	259	2.62

Particulate Emission Factors for LD Vehicles

	'75 FTP (mg/mi)	SET (mg/mi)
LDD 1976 Model Year	490	350
Olds Cutlass Diesel	922	579
VW Rabbit Diesel	293	259
LD Gasoline Pre-1973	340	-
LD Gasoline Cat. Vehicles		
19751976 California	10	40.4
19751977 49 - State	-	22.8
VW Rabbit Gasoline	6.2	2.6

duty diesels in-house in Ann Arbor. Here we found the average emission rate was about .5 grams per mile. The Olds was much higher, and the VW much lower.

Light duty gasoline cars, pre-catalyst, had a relatively high particulate emission rate of about .3 grams per mile, most of which consist of lead salts.

The catalyst cars, which are the last cars listed on this slide, are relatively low in particulate emissions as I have already mentioned; and, here again, most of the emissions here are small quantities of sulfuric acid.

In this work, we also measured a number of other emissions, such as aldehydes. Here we found the diesel versions were generally the same as the gasoline version. The Olds diesel, though, is a little bit higher than its gasoline counterpart. We measured methane in the exhaust. The methane is a relatively non-reactive hydrocarbon.

Both diesels had about 3 percent methane in the exhaust; whereas, the catalyst cars had about 30 percent methane. Therefore, the hydrocarbons from the diesel would be expected to be more reactive photochemically than those from the gasoline versions.

The sulfates from the diesels were relatively low. There was about a one percent conversion of the relatively high fuel sulfur to sulfate, but the overall emission rate was about 10 milligrams per mile for sulfates.

Benzo-a-pyrene from the two diesels was about 4 micrograms per mile, and this is about the same as a non-catalyst car. So, from the work we see the comparison between the diesel and the gasoline cars.

We plan to do a lot of future work on the light duty diesel, looking at the effect of various fuels in even more detail than we have before on the particulates.

The fuel work that we are just completing now addresses mostly particulate mass emission rate. Our future work we hope to to emphasize organic emission rates and reactive compounds. We, also, plan to look a little more at bioassay activity on the Ames test than we have in the past. We will look at such fuel parameters as CH ratio, aromatics, sulfur and nitrogen compounds present in the fuel, boiling range of the fuel, look at blends perhaps of diesel fuel with small quantities of alcohol or water emulsion, cetane number of the fuel, residue level of the fuel, and finally, some additive packages.

In the heavy duty area, we plan to concentrate a lot of our work in the future on the newly developed transient engine cycle; and this should give us numbers for the transient cycle versus the steady-state 13 mode, which we have already characterized.

That concludes my comments.

PROF. JOHNSON: What I would like now is to have all the panel members come up here in front, and we will go to the panel discussion portion of the program.

All these gentlemen you have met; they have been speakers. First of all, before I open up to questions on the floor, I would like to ask the panel, as they have sat here and heard each other's speeches and a number of other talks here, whether they have any particular issues or any particular thoughts about some of the things that have been said that are important that we bring out and discuss initially, about the characterization of emissions, particulate emissions or odor from diesel engines.

If there are no comments, I have got a long list of questions here. I see the overall direction which we will probably see as we get more into the other day's session of going to characterize and the need to characterize this organic fraction that Joe alluded to, and I talked about it myself. How can we get a good engineering measure in a laboratory from a research viewpoint with reasonable techniques? Jim talked about how important it was in the atmosphere to do it. Dick alluded to that, but I see the need to chemically characterize this organic soluble fraction.

How can we work towards reasonable procedures, analytical techniques that are feasible even on a research basis, to get a good measure that we can characterize engines in the laboratory with. reasonable techniques that don't introduce artifacts so that we know that we have some kind of an engineering number, because, when we get into the control this afternoon, we are going to have to have some number to measure and to do any engineering development work.

Jim, will you start out the morning and kind of set the stage?

PROF. PITTS: First of all, let me emphasize that I think communications can, and must, exist between the chemist, the engineer, and the biologist. It is essential to think in a multidisciplinary manner and to pick some specific targets and go at them in an organized manner.

Now, I would like to address Dr. Wheeler's comments. Some of these techniques can be fairly straightforward and direct, but others have to be quite sophisticated approaches in order to lay a foundation of detailed laboratory experiments.

For example, consider the separations you have to go through in order to identify some of the classes of compounds present in a sample of particulates. After collection, the sample must be separated into an acid fraction, a basic fraction, and a neutral fraction. The neutral fraction is then separated into polar and nonpolar aromatics, then thin layer- or high pressure liquid chromatography is carried out on each of these fractions. Combined gc-ms analysis is then done on these bands as they come from the chromatograph.

The Ames microbiological bioassay can then be used to further characterize chemically these mixtures of compounds. But a single assay with one Ames bacterial strain is not enough. There are five strains and all five should be tested. For example, use of strains TA1535 and TA1538 can tell you immediately whether one has a base pair substitution mutagen (TA1535) or a frame shift mutagen (TA1538) Further, one should generate dose-response curves for each strain.

Finally, a metabolizing solution (S-9 liver homogenase) must be added to each sample so that promutagens, such as BaP, can be detected. One should also generate a dose-response curve in which increasing amounts of S-9 solution are added to the sample and the effect on mutagenic activity is noted. In this way one can determine the optimal amount of S-9 solution to add.

To add a further level of complexity, remember bacteria don't get cancer. One can't extrapolate from mutagenicity in bacteria to cancer in man. This is a very complex procedure, but it yields crucial information.

PROF. JOHNSON: Would you take the microphone please, and give your name. Also, when we get into the audience comments here, I would like to have you give your name and your organization.

MR. HURN: I am Dick Hurn from the Bartlesville Energy Center of the Department of Energy. Jim, that is a very good discussion of what needs to be done generally; but John Johnson asked the question what can we in the laboratory do in a relatively simple engineering test to get at some of these materials that need to be measured, and I really think we need to address that before we go into the more complex studies of the characteristics of the materials. I really believe it is a very, very critical question.

PROF. PITTS: I agree. However, let me point out that there are two general ways to approach the problem--with rapid, simple tests, or with in-depth, complex tests. But it appears to me that in order to decide which test one should use, one first has to formulate the questions one wants answered. If the question is a relatively straightforward one, for example, how to measure the total mass of particles per cubic meter of air irrespective of particle size, a good engineer or chemist can readily tell you how to do it.

However, if the question concerns identifying that group of chemical compounds from the exhaust from the most common German car (referred to in my talk) which may be responsible for inducing pulmonary tumors in mice, then that is a very different matter. This is the type of question that may well be asked by the EPA or Ms. Claybrook or the public or someone in the National Cancer Institute. To answer it, some very complicated and expensive chemical, microbiological, and even clinical experiments will be necessary.

In sum then, the questions first have to be defined in order for us to find the answers. How is that for a professor's way of turning it around?

MR. WHEELER: I take that absolutely. When I was making remarks about chemists, I was not intending anybody else to listen except the EPA people. What I was saying was on behalf of the poor old industry; and after all, the diesel industry has got a long way to come in a short time, and I am really pleading for them to be given time. The gasoline industry has been going at this since about 1966. Diesel engineers have only just heard about this thing, and you cannot believe what a sensation amongst our clients the Ames testing has caused. In Europe we have had people coming to u[illegible] the deepest gloom about it, and we have had to explain this. [illegible] have taken advice from the best authorities we know in Britain. We discussed this, and now, looking back at it, there are always many sides to any topic. I can tell you a little story which brought me up with a bit of a start, and that is going on to Jim Pitts side for a change. I had to go and ask opinions of some pathologists and people who were wise in microbiological testing and knew all about the Ames test and did it specifically in food products and things of this sort. First of all, they assured me it was a jolly good test, and it was very significant and had been useful in the industry, and anybody in the industry who sold products worldwide without using Ames testing was asking for trouble.

Then they said to me, "Okay, so it has hit the diesel engine. It is hitting everything. So, tell me how much of the material which is likely to be giving Ames tests does a diesel engine give?"

So, I said, "Well, looking out at the street," and it was a street in London, I said, "That is about a mile long. A London taxi will give, if it is in jolly good condition, and its injectors are all clean, about half a gram of particulates going down that street."

Now, these fellows said, "Heavens, as much as that?"

So, I said, "Wait a minute. If I had said that to a group of engineers, they would have said to me, 'What in hell is all the fuss about? Half a gram? That is nothing. We are dealing in pounds. You know, we deal in weights of a piston or a con rod or a crankshaft. Half a gram is peanuts.'"

I said, "You explain that. Why did you say that?"

They said, "Well, look, each particle, if it is a combustion particle, it is about half a micron, maybe, and that weighs 10-9 grams; and we are dividing that into your half gram, and it is a helluva lot of particles all containing possibly toxic material."

That is really the difficulty of the two sides getting to understand each other; and if I took exactly the opposite side, the engineer's side at first, I apologize. I come down in the middle.

PROF. JOHNSON: Joe?

MR. SOMERS: One thing that we feel is fairly important at EPA is to get an assessment of how some of these compounds change with different engines. At this point, all of our work has been done on just particulate mass, and to some extent soluble organic fraction; and it is just now that some of the work is beginning to start to separate the various components of the soluble organic fraction into species that may be responsible for some of the activity we are seeing.

It, nevertheless, appears to us that one of the very important things to do in the next several years is to look at some engines, as well as some engines with various control systems, and see how these control systems affect the reactive fraction.

One thing that may very well be possible is that a diesel and a catalyst may have a completely different type of particulate than the diesel without the catalyst. The catalyst may, in turn, do something to the hydrocarbons to change them substantially. This is a question to which we really don't have an answer, and one which we are working on right now, as well as a lot of other people.

PROF. JOHNSON: The question that I am concerned about is, I realize what Merrill says in terms of the kinds of decisions in the short term; but when you really expend all this effort, analytical effort to characterize the organic fraction, it becomes very important to know that you are really getting what is out there with these individual particles at 1000 to 1 dilution ratio out in the atmosphere and that you are not introducing artifacts or doing other reactions on the filters. So, how do you, from an engineering viewpoint, collect these and use and spend all this money on Ames test or all this analytical time in the laboratory, very extensive, even on a research basis, the collection and the very time-consuming problem of analyzing it and then these numbers that are reported possibly might not have any meaning to the real dose out in the field. That is the serious problem I see.

MR. SOMERS: I guess the question of the measurement method is something on which you could always do work. What we have done is looked at the dilution tunnel, a fairly standard method of collecting particulates and looked at the characteristics on the particulates once they are collected.

Some work is also underway to look at artifact formation of various compounds on the particulates; also, what happens to some of these compounds with time, how stable are they, what is their reaction in the atmosphere, and items like that.

A lot of the atmospheric kind of work in this area is being done by the EPA Office of Research and Development rather than by mobile sources; but, nevertheless, it is very important work and would answer some of these questions.

PROF. JOHNSON: Maybe this is a good time to open it up to the floor.

MR. HANK: I am Mike Hank, and I am with UOP. I would kind of like to restate what you have said. It seems to me that it looks as though you are headed toward setting a particulate standard without having a correlation between that standard and health effects down the line. Maybe some of this will be addressed tomorrow, but that is a separate possibility, and that leads to what I think you are trying to get at, and that is given that there is a relationship between the particulates you are going to measure in a given test and health effects, where then do the auto makers or the engine makers go to reduce the danger of health effects? We make catalysts, and what should we look for in terms of the catalyst? What should it accomplish? What should it get rid of or what should it avoid forming? We need some guidance, and I am not sure how the heck a guy who is figuring out what kind of engine to make in 1983 knows what to do. He has got some lab setup, but what is the aim now?

PROF. JOHNSON: Who would like to take a whack at that? Merrill, would you like that? You are looking at the short term here.

MR. KORTH: I can certainly share the bewilderment. I guess as far as we are concerned in the short term, we are talking about total particulate and total particulate to me means carbonaceous materials, plus all of the organics, whatever they might be, and at this time, certainly we need a lot more information in that area.

From the short term regulation development standpoint, we felt that it is important that we get some measurement of the organics, even though the two flame ionization units that we are using together may not be the perfect or the final best technique. It is something that now, when we are getting baseline emissions, we can use to get some comparison over the vehicles that are being tested. There are some differences in control technology, or at least vehicle technology, among the vehicles that we have operating up to today; and based upon some of the characterization data, what you might reason out, not only the total particulates would be expected to be different, but possibly the organic material.

As to where we will end up one year, two years, three years from now, I hope there will be much more information on the question; and we can come up with better techniques and better guidance, but at this time I don't know who is going to supply it. That is why some work needs to be done.

PROF. JOHNSON: Okay, do we have another question? Any other questions? Okay, in the back, Barry?

MR. McNUTT: Barry McNutt, Department of Energy.

Merrill, did I understand from what you said, is the standard you expect to be set or the proposal for later this year going to be a total particulate standard or an organic? As I read the act, it says, "Total particulate," but I think that you would have to agree that a lot of the concern is with the organic materials involved. My concern is that both as an agency for us and for independent researchers, where do we put our effort? Are we suboptimizing or wrongly directing our effort in looking at total particulate or reduction in total particulate as opposed to reduction in organics? This is the same question the gentleman from UOP really asked. Is the first standard that EPA sets which will be on the books and is going to be a guiding thing for research into the fut future going to be directing us in the long term direction we want to be going in terms of dontrol technology research? Do we have enough characterization information now to go ahead and start that research?

MR. KORTH: Total particulates. To repeat what I said earlier, to me, total particulates are organics plus the carbonaceous material. I would love to have a good way of separating the two; but at this time, we don't, and we are going to do something. The Act says that we will have a regulation.

MR. SOMERS: It appears that there is some correlation, in fact, a fairly good one between total particulate mass and the organic fraction. There are some exceptions to this. In my talk I mention that the two-stroke cycle diesel bus engine had a very high organic fraction, but this is somewhat unusual. All the other diesels, as a rule, have an organic fraction of about, say, 10 to 30 percent, roughly, and with that in mind, any reduction in total particulate mass should also result in a reduction of the organic fraction, although it may not be in exactly the same amount. Nevertheless, the trend will be there; and thus, any standard based on total particulate mass will also control the organic fraction which is the one we are mostly concerned about.

PROF. JOHNSON: Wouldn't you think, though, Joe, that more of the organic soluble would be related to the oil consumption and the design and also the gaseous phase hydrocarbons? I would think that the soluble fraction would be more relatable to those parameters, and it just happens to be a coincidence that you are talking probably about the same oil consumption and the same hydrocarbon levels of vehicles. I would think from a technical viewpoint, it would not necessarily hold true; and I think what Barry is talking about is if the whole direction is in the organic solubles in the long term, you know, the concern, and as Dick Wheeler said, this carbon, this solid fraction is very hard from an engineering viewpoint to control, what is the end point that engineers should be working at in terms of doing the development and the research to get the right control, to control the right fraction of particulate matter?

MR. SOMERS: I guess you could look on this, maybe, as a two-phased approach. Initially, the emphasis is mostly on particulate mass, and then, as you go further on down the road, particulate mass and some of the organic fraction, and then as you go further on down the road, everybody should know what is responsible for some of these reactions; and thus, the emphasis should change, and you make a very good point, John, that there is really no quantitative exact relationship between the total mass and the organics.

This is why I said the range was roughly 10 to 30 percent. There is a fairly wide variation there. Nevertheless, there does, at this time, appear to be qualitatively a fairly good correlation between them. So, I think my feeling is it would depend on the time frame.

PROF. JOHNSON: Did you want to comment, Dick?

MR. WHEELER: Yes, I wanted to reinforce what John Johnson had said, really, that there is a great difference in type testing good engines which are well set up and what is the real problem which is diesel engines on the road, and this afternoon I hope to tell you a little bit about what we are doing in that respect on defect problems in diesels. You can get a very much worse relationship between the carbon and the hydrocarbons with very simple small defects in the diesel. I would fully agree that probably if you can reduce total particulates you are reducing the toxic element, but I think it penalizes the diesel because you can work hard and get your particulates down 10 percent, and you have really done very little to your toxics. If you have got to attack the whole thing, then you have really got to attack the carbon. That is the one you cannot attack easily. The hydrocarbons, the toxic material you can attack fairly readily; but if you do, and you remove them completely, you are only going to get (on a well-regulated type tested engine)) as Joe says, the value down by about 20 percent if you do a 100 percent job on the HC's and you don't touch the carbon.

PROF. JOHNSON: Just to give another frame of reference, there are about 108 particles per centimeter cubed of these soot particles, just as a frame of reference to go with your half gram. That is how difficult the problem is.

Okay, we have got a question.

MR. SCHRECK: Richard Schreck from GM Research. I would like to make two points with respect to this question of organics. One, we found quite a bit of variability in the percent organics with load exhaust temperature and things. So, maybe it all averages out in the FTP, and maybe it doesn't. It is probably too early to know yet.

Another question for Merrill. I was wondering if you have got any results yet on your hot filter hot FID rig versus your cool filter hot FID line. You said that would be one way of looking at the percent organics on the particle. Have you got any test results from that yet?

MR. KORTH: Yes. We have been routinely collecting that data along with the total particulate by the filter. Some tests have been run at Research Triangle Park by Frank Black comparing the difference between those two hydrocarbon numbers and the amount of organics you get when you extract filters collected on the same test, and he found very close agreement with the two techniques and recommended that we use that as a routine engineering type measurement on our baseline study.

Extractable organics by chemical techniques and the difference between the two hydrocarbons, in other words, the delta hydrocarbon or the two flame ionization readings, compared to the total mass of the particulate or the mass of the particulate or the mass of hydrocarbon you would calculate from the delta hydrocarbon.

PROF. JOHNSON: Another question? Jack?

MR. NINOMIYA: I am Jack Ninomiya, Ford Motor Company. I would like to direct this comment to Merrill Korth regarding recommended practice for light duty diesel particulate testing. I read the document, and I have also followed the heavy duty particulate cycle development at EPA. My major concern I would like you to comment on is that I recognize the importance of a detailed, sophisticated instrumentation and procedures for characterizing particulates from diesels, and I recognize the wonderful work that EPA has done so far; but my main problem is that when you have established the certification procedures for these engines, it appears that EPA is taking this research procedure directly into the certification cookbook type of procedure without much of a change, so that the manufacturers of engines are required to equip themselves with detailed tunnels, two heated FID's, dual filters, and I think this makes it overly complex for the engine manufacturers to certify their engines.

Now, let me give an example. For instance, the mass median equivalent diameter of diesel particles has been stated to be less than half a micron. So, my question is, is it really necessary to have isokinetic sampling, using a huge tunnel, and I think what I am trying to say is that is there any way to simplify the particulate measurement system, at least for certification purposes?

MR. KORTH: I have two reservations on what you say, Jack. The first is that I don't consider the technique that is being proposed as a complicated approach. The dilution tunnel is big, but the rest of the system is essentially a CVS. The dilution tunnel is a large pipe that is added between the dilution box or the mixing point and the metering pump. Maybe that could be smaller. I don't know. Time will tell as we get more data. Maybe we will get some from your company that will demonstrate that really it is not necessary to have such a long tube or a tube so big around, or maybe not even necessary to hold so closely to the 125 degrees Fahrenheit; but at this point, we don't know that. The procedure is based upon what we feel we are confident of.

A research procedure? I don't think it is that complicated. The variability in weighing the filters is not large. So, I think that the variability you see with the procedure as proposed won't be any greater than what we are seeing with the present regulated pollutants. Does that get to your point at all?

MR. NINOMIYA: Yes.

PROF. JOHNSON: Any other questions?

MR. MANTEUFFEL: Manteuffel from Daimler-Benz. I would like to come back to the introduction this morning.

Isn't the purpose of this meeting to establish whether the diesel engine introduces a greater health hazard than the gasoline engine? So, isn't the question really what benefits do we get from the diesel in terms of emissions and what disadvantages do we get and compare those to what we have from the gasoline engine, and I am particularly unhappy about the discussion and also the measurement technique draft proposal going in the direction of paying attention to the hydrocarbons attached to the soot particles.

Now, let us put the problem into perspective. Any of our diesel cars today emit less than .4 grams per mile of hydrocarbons in the official test, .3 or thereabouts. We find that a fairly constant and fairly small percentage of these hydrocarbons attach themselves, adsorb onto soot.

Let us take a guess, let us say this is 10 percent, if it is high, and this is on the order of .03 grams per mile. Now, we find that 1 percent out of those are polynuclear aromatics, and again 2 percent out of those polynuclear aromatics have been identified as benzo-a-pyrene, which is 2 10/100 or 1/5000 of the polynuclear aromatics. All in all, the total hydrocarbon emissions of a diesel engine, presently anyway, bearing in mind that they are generally consistent over engine life and you can find that low in hydrocarbon emission even at a mileage of 200,000 miles on one of our diesel cars. Bearing that in mind, are we not attaching too much attention to the last 10 percent, and coming back to the BaP question, do we not have to ask the question, is the BaP emission of the diesel at all higher than that of a gasoline engine? There are indications that it is lower. Is it not advantageous? Do we not have to ask questions like, are the hydrocarbons freely floating in the atmosphere more dangerous to human health, or is it not possible that in the case that they are attached to soot, that they are less dangerous to human health?

We have, fortunately, found on our diesel engines that the particle size mass distribution is such that 80 percent of the particles emitted are in the size range between .1 to .3 microns.

Now, this happens to coincide with the size range for which th the human lung has the least ability to retain; in other words, the human lung retains very large particles in the upper respiratory system. They cling to the hairs in the throat. You can cough them out. The very small particles are inhaled and go down into the lower alveolar region, but this medium size follows the flow of air in and out. It is inhaled. It is exhaled, and the retention capability of the human lung is lowest; it is actually a curve like this, about 20, 25 percent in this very size range where the diesel particles, at least of our cars, to be precise; but I do not expect other diesel passenger cars to have largely greatly different size distribution characteristics, have their maximum.

So, if you put all this into perspective, we feel that, and we are really talking about the measuring procedure this morning, we feel indeed, and I am now coming back to what has just been said, the extra effort for the extra heated FID, justtto find out how many hydrocarbons are now attached to the soot particles does not pay, is not justified.

Anybody who has played around with heated FID's knows the problem, and we would hope —

PROF. JOHNSON: Could you get more to the point of your question, so that we can —

MR. MANTEUFFEL: I have not really a question. I am making a statement. I am participating in the discussion.

PROF. JOHNSON: Could you summarize though so —

MR. MANTEUFFEL: If you will permit, and I think previous speakers have, also, commented in a similar fashion and have not always asked questions; but with that, I am really through.

PROF. JOHNSON: Okay.

MR. MANTEUFFEL: Thank you.

PROF. JOHNSON: Let me just make a comment. I think that the objective of the whole two-day workshop is, as you stated, to look at it. I think that we have tried to delve into the engineering, and also, to focus on this system. As Jim mentioned, there has got to be feedback from the environmental aspect and from the whole simulation problem; and I think we are, in this session, trying to zero in. That is why I raised the original question about the engineering aspect. We are trying to get all the issues out on the table; and I think that we are not, in this session, weighing all the pros and cons of the diesel. I think it was started out in terms of talking about the fuel economy and some of the other advantages. It is in the open literature. I think the objective of this session was to talk about the state-of-the-art and talk about the problems from a research and from an engineering viewpoint of looking at this part of the system. As I see it, I would be glad to let somebody else take a whack at his comments, if

Dick, would you like to?

MR. WHEELER: I have the greatest sympathy with the last speaker, but I would assure him that I, personally, regret last year's Congressional decision to push this so fast, on the basis that the research work just has not been done. It is unfair to expect people to regulate something which is an ephemeral thing. We just cannot put numbers on it. We cannot even measure it properly. Nobody has researched diesel engines enough; but it wasn't only last year's Congressional Committee. Already there is a very big movement in NIOSH. For instance, anybody who was at last year's NIOSH Meeting, which was concerned with whether, in fact, diesel engines should be tolerated in American coal mines or not will know that we went through all of this for several days there; and, again, the conclusion we have come to, although I have not seen the NIOSH report, is that there is a great lack of knowledge. Other people also, for instance, the American Mining Congress, have taken a look at the whole thing as they are very much implicated in this; and they, obviously, want diesel engines in mines. It is the only way to make an economic mine. They have had a great deal of work done in this area, and there is a very good report out which, again, reinforces this opinion that the work has not been done. There is no good data to base anything on at the moment. We really need five years of energetic research into the diesel engine to see what we can do with it.

Nobody really knows, and the first thing we have to do is have some common agreement which the EPA people are trying to get on simple test procedures; but I only would like to make the plea that they be simple, and I would agree with the last but one person from the floor who made also this plea that we do want simple procedures, but there is a frightful lot of work to do.

PROF. PITTS: I wanted to comment on this question of finding "simple" procedures. This is highly desirable, but there is also a bit of a problem here. If one makes the procedures too simple, then the data one collects might later turn out to be useless. For example, in the opinion of a number of people involved in the atmospheric sciences, including the medical, physical, chemical, etc., aspects of it, the idea of going out in ambient air and collecting simply total suspended particulates--including large particles of dust from natural sources with fine particulates from auto exhaust--and then specifying a Primary National Air Quality Standard in terms of the mass of that diverse mixture just does not make sense today. It made some sense back in 1967 when we did not have straightforward fractionating systems that we could use. Then the simplest way to collect these things was altogether on a Hi Vol filter. Today we know that any particles over several microns are not going to be deposited effectively in the lungs; hence, they will not have a health effect. So, you have enormous amounts of data from filter samples collected at many stations during the past two decades that may have no correlation whatsoever with the very effect you are trying to study, impact on human health.

Clearly, one needs to collect data for particles in the respirable range. Now there are available various samplers which allow size fractionation of the ambient samples. Some of these are quite simple, by the way. I understand that one has been developed which will sell for under $1000. So, apparently, for under $1000, one may be able to get the desired size fractionation quite nicely and, thus, answer some of the key questions on impact of particulates on health and visibility.

Clearly, it is a two-headed question. One wants to make the procedure as simple as one can, but the resulting data must answer the question you are asking. If the simple procedure won't answer the question, you are in another bind. One has to go to complex, time consuming and costly approaches.

PROF. JOHNSON: There is some balance point, I think.

PROF. PITTS: I think we can achieve a balance. I think this would be a perfectly appropriate thing to do.

PROF. JOHNSON: And we need to pursue research and this loop, this feedback that has to occur back to engineers in terms of trying to improve upon the state-of-the-art and use state-of-the-art techniques that are simplified, that are a compromise in terms of the particular problem at hand.

I would like to comment, Dick, the NIOSH Proceedings are out now, just to expand upon it. I suppose it takes a little while to get over to Great Britain from the United States.

MR. WHEELER: They ship them by sea sometimes.

PROF. JOHNSON: Another question in the back, Phil Levins?

MR. LEVINS: Phil Levins from Arthur D. Little. John, I would like to take the liberty of commenting here, if I might, on characterization methods generally. There is such a large gap between what Jim would like to understand the mutagenicity testing results in his studies, and I am fully sympathetic with what the certification people would like in terms of a simple, reliable, well established and proven procedure. We have to iterate around, and we have to establish standards so someone will get off their tails and start moving; but we are a pretty intelligent community, and all you engineers know full well what is going on in the chemistry laboratory, and I am a chemist. I have some concept of what you are doing in the engineering laboratory as well, and there is a little bit of a discussion going on here that kind of says, "You engineers will never understand any chemistry, and for heaven's sake, don't put any in my engineering laboratory, please!" I would like to address that part of the question a little bit, since the focus this morning is presumably on characterization stuff.

The diesel engine, as you are all well aware, is a very complex chemistry machine in terms of the emissions it puts out. We focused so long on carbon monoxide and NOx that those look relatively simple. We don't even still fully appreciate the toxicology of those straightforward species. There is a wide range of other things that come out, the methodology for the measurement of things like the aldehydes or formaldehyde, acrolein for deodorants, for the phenols that come out, certainly for the polycyclics, are not well established yet. There are methods and procedures that people are using. The methods are inadequate in almost every instance. They are internally consistent, usually within a set of experiments. So, if you look for a percent reduction across the system, the aldehyde method may be reliable for that, for instance, but in terms of making absolute concentration determination measurements so that we can take the emission data, the dilution ratio and hand it to Jim and say, "Is this going to be mutagenic in a system?" that requires absolute data. Most of the methodology does not exist there yet. So, we need to develop our general package of methodology for measuring emissions in what is, admittedly, a very unstable, very reactive medium, the diesel exhaust stream. It has got a lot of hot stuff, and everybody has been literally burned, and figuratively, when they go to measure these things. The PNA's are certainly the best example we have probably currently of a procedure that requires 10 to 400 factor correction factors to get data out of it.

Jim needs 6-nitro BaP data from the analysis to do his interpretation of the mutagenetic effects. You guys would like to work with grams of particulates. There is a lot of in-between land, and the in-between land is the hierarchy of analytical method development that is being worked on in several other problem areas. For instance, parts of EPA are developing a phased analytical approach to try to help address the issue of source emissions and health effects on the two extremes and bring them both together.

We need to develop our measurement methodology, our health effects understanding of the chemistry provided by those measurements simultaneously. We have neither of them now. We have some tools that we are starting to work with. So, we are way behind, and we are all going to be frustrated for the next five years while we complain that this guy did not give me that, and he did not ask me the right question kind of stuff, but we are all in the same boat. We ought to fully recognize that.

There are presently some techniques that can help us make the next step; and as we learn a little bit, we will go along to the next one after that.

The thermal analysis procedure for analyzing the amount of hydrocarbon adsorbed on particulate that Dick showed us this morning is a nice, simple technique. Thank you, Dick. I like that idea. It is not complicated. You engineers can learn to run that, surely. It is harder than weighing a particulate on a filter, but weighing particulates on filter is as unreliable as you can get. You know, it just does not give you good reliable data if you want to get serious with the problem.

There are some other techniques. The work that we did on diesel odor developed some methodology which allows you to look at those soluble hydrocarbons that are on the filter and classify them very simply into a couple of major groups, a fuel related group, the aromatics and a partial combustion product related group.

Now, the chemistry in each of those groups is very complicated, and we need all of the scarey kind of stuff you know the single sample giving 40 fractions for GCMS analysis and it costs $200,000 every time you analyze a sample. That stuff needs to be done. It needs to be done to develop a baseline of data; but once the baseline of data is available for things like the aromatics or things like the aldehydes as a group, then the baseline does not change very much; and you can use — you can regress if you will — in your analytical methodology to simpler procedures.

You can go back to MBTH procedure for aldehyde and use that to measure concentration level changes as long as there is a data base someplace else that says, "I understand what those aldehydes are for the most part most of the time, and if I have some unusual data, I am going to go and check the detailed aldehyde composition to see whether it has changed from what my baseline was," but there is a need then to develop a hierarchy of analytical methods and the procedure is available for doing that now, some simple infrared and UV techniques, for instance, some LC techniques. You can get into mass spec if you want to, but this audience as a whole has no justification for doing that. Then you need to develop the baseline data, and then you do need a full bore of analytical procedures to generate that data; but you can bring the two pieces together and reach some middle ground, some compromise that will keep everybody a little bit unhappy but will develop enough more data so that Jim can look now at concentration of five pieces of information emitted from a diesel engine and say, "Oh well, maybe that group is more interesting to me than just total grams of particulate." There is already some methodology that allows us to isolate out of the PNA group, for instance. You can separate the pure PNA's from the oxidized PNA's and kind of find those out and run your Ames test on those separately. That methodology is really not very complicated. It is probably a lot more reliable than some of the hydrocarbon measurements you are making routinely, too. You all know how bad those are. It takes a new technology. It has to require letting the chemist into the engineering laboratory to make it all work right, but there are some relatively simple techniques that you can use routinely, as well as the complicated ones that you need to develop the baseline with, and I am just making appush for people not to be intimidated by the chemistry of this admittedly very complex stream.

PROF. JOHNSON: I think you were just sort of making comments. I would agree that chemists and engineers are doing work together. I think the problem in the United States, and the societal problem, is that, in the meantime, there are business and government decisions that have to be made because of the concern about energy conservation and because of the concern for the environment. Congress has reacted by requiring a standard in 1981; and so, the problem is that in this time it really forces business, engineers, and chemists really to work together. I think, to solve this problem, because there are some chicken and egg effects between the atmospheric things that are going to happen, and I think what has evolved in the 1970's, and it was brought home to me at the NIOSH Symposium and maybe all of you don't agree with it, but that the people that are responsible for technology have the responsibility to prove before the fact, before the large introduction of technology out into society, what are the cause and effects and what are the potential problems before it is put out into society in large numbers.

I think that is the problem, why it makes it so difficult for engineers and people in government and in business, chemists and everyone because we are having a tremendous crunch. I have been in this business since 1974. People accuse me, because I am doing research, of heightening the national concern for particulates. I think that, obviously, Congress, in passing the 1981 standard requirement in August, 1970, did a lot more than any research person could do back at a university, particularly, in the Upper Peninsula, where we have a lot of snow; and it is remote; but I think that is the problem, Phil, that we are faced with and that is really the problem of this two-day Workshop that I think NHTSA and other people in industry are faced with, is that there are allot of important decisions that have to be made now. We cannot wait three years or fiveyyears to make decisions. There is a lot of important business and government decisions that are being made, and that is really the purpose of this Workshop, as I see it and as Sam Powel mentioned earlier, this will be the record of the state-of-the-art now, as a result of these four days.

I think it is getting to be 12:15. Dick, I will give you 30 seconds here, if you would like to make one comment.

MR. HURN: I would like to make a request, John. All of the speakers for this afternoon, those who have presentations to make, stay here very briefly after we adjourn this session.

I would like to ask one quick question, and I think it can be very quickly dispatched, John. Does anyone, particularly EPA, have any view on whether or not we can justify spending time and money and available resources today on attempting to differentiate at the tailpipe plane those hydrocarbons directly attached to and associated with the particulate and that is free floating in the gas stream?

PROF. JOHNSON: Joe, would you like to take a whack at that?

MR. SOMERS: Yes, I think that some work should certainly be done in that area. The major emphasis of our work, though, is to collect the particulate samples with the dilution tunnel, refine that method as necessary to simulate what would occur in the atmosphere and see what happens, but other approaches could certainly be used.

PROF. JOHNSON: I would like to thank all theppanel members and the audience and all the other speakers for a fine session. Sam Powel has a few procedural comments to make before we break for lunch.

(Thereupon, at 12:19 PM, a recess was taken until 1:26 PM the same day.)

AFTERNOON SESSION

MR. HURN: Gentlemen, the 5 o'clock departure time for aircraft for those leaving this afternoon will come sooner than we want. I do expect that we will move right along in the afternoon session, with a break sometime after about the fourth paper, probably.

We have had an interesting discussion this morning about measurement characterization of diesel emissions. This afternoon we will discuss control technology, some of the options and technological possibilities we have for controlling emissions; and I would hope some information on the implications of that for the acceptability of the diesel.

I believe I would request that, to the extent that the presenters can avoid expansion of their remarks into the areas of philosophy, I think that this is not altogether productive at this time. We would hope that we can focus upon the technological issues.

I have been asked to request that those of you who may not hav have registered, that you do so; and I would even suggest that you do so at this time because, otherwise, you might forget, and the sponsors of this Conference do wish to have a complete list. This is for your benefit, as well as theirs, so that you can get information that will be sent forward.

This afternoon we will depart from the order as shown on the agenda, and let me give you that presentation order in order that you might be able to anticipate. The first presentation will be the GM presentation on "Comparison of Diesel and Gasoline Engines in Passenger Cars." This will be followed by John Johnson's "Overview of Control Technology." The third presentation will be "Characterization of Diesel Exhaust" by Mr. Dies of VW. The fourth will be the presentation by Mr. Cornetti of Fiat, "Measurement of Unregulated Emissions." The fifth is the paper by Ed Barry of

Mobil. The sixth presentation will be that by Karl Springer, "Diesel Exhaust Particulate Trapping;" the seventh following, as on the agenda, "Soot Filtering." The eighth, Dave Dimick's discussion of "Particulate Control Development Status," and the concluding presentations, those having to do with work in the Bureau of Mines program and some brief comments about work at DOE. That work to date has been primarily in support of the Mines Safety Program, and that is the reason for connecting those two.

The first presentation then, as I suggested, a review of the GM information in which they have compared, I believe it is performance in the diesel and gasoline engines in passenger cars, Chuck Elder.

Chuck?

MR. ELDER: Thank you, Dick. As I am sure all of you are aware, General Motors has been very much involved in the work toward a diesel engine for application to passenger vehicles. Throughout that process, there has been continuing discussion of the relative attributes of diesel engines versus gasoline engines as they are applied in normal passenger service.

What we tried to do was set down a number of areas where there are distinct differences and where there is interest in comparing the capabilities of the two engines. Shown in this first slide is a listing of a number of the areas which we have reviewed. These are written up in more detail in a paper which has been left for file. I will plan to go through a few of the subjects in a little more detail here today. These include a number of environmental issues; the gaseous emissions, the hydrocarbon CO and NOx emissions are very important, the evaporative emission differences, the particulate emissions, the susceptibility or probability of maladjustment and tampering in the field which has become a very important parameter of performance, the noise level of the two engines. In other areas, from the safety standpoint, the potential for vehicle fires, the relative energy requirements, the use of natural resources, in particular, critical materials, relative reliability between the two engines, both in terms of ability to manufacture the engine correctly in a reliable fashion and from the customer's standpoint, the serviceability from the customer's standpoint and, of course, customer cost and customer acceptance.

I would like to review just a few of these areas, not trying to cover all of them to save time.

Could I have the next slide, please?

One of the main areas, of course, is the gaseous emissions, the exhaust emissions. If we look at the 1980 and 1981 requirements, in 1980, for the .41 hydrocarbon, 7 CO and 2 NOx, of course, the gasoline engine will typically, add at least, totally in our case, utilize an oxidizing catalyst. This system for 1980 is going to need to be more efficient than our current systems. We will probably need to have some kind of air injection system.

For the diesel, however, at these emission levels, there really are no external controls required. The hydrocarbon levels are going to need to come down significantly from where our current production engine is operating, but this does not look like it will be done or can be done with external controls. We really have to do it within the engine combustion process.

For 1981, the standards are .41, 3.4 and 1 noted is the 1.5 for NOx on the diesel — there is some interest in requesting a waiver for the diesel because of the EGR requirement for NOx.

In the gasoline engine, these standards get you immediately to a reducing catalysis requirement, either through a dual catalyst or a three-way catalyst. I will not go into these in any detail, but the primary difference in the systems is the ability to meet the carbon monoxide; the low carbon monoxide standard determines whether you need the dual catalyst or not.

For the diesel it does appear that it is probably going to need to use some amount of EGR to reduce the NOx level of the engine. At least our experience with the Olds 350 engine indicates that that size engine and that size car is probably going to need some EGR to get its emission levels down.

Use of EGR, as has been mentioned earlier this morning, does tend to increase hydrocarbons and particulates so that is a negative impact of that kind of control.

Could I have the next one, Sam?

Another interesting area in the environmental performance or air pollution performance of the engine is the high mileage performance difference between gasoline and diesel. By this, I mean the performance after 50,000 miles in the later life of the car. How is the system going to perform?

In the catalyst system, of course, it does age with life and with use, and you can expect to continue to see some aging of that system and some degradation in performance.

The diesel, however, based on all our experience so far with the engine, we really expect the emissions to be stable. Now, there is a question about the use of EGR and its possible impact on the long term durability of the engine and whether that will have an emission impact. But the engine itself does certainly look stable at high mileages, and that is a real advantage.

May I have the next one, Sam?

The next one is on evaporative emissions. This is another area where there are really major differences between the gasoline and diesel engine.

For the gasoline engine, if you convert the 6 grams per test requirement to grams per mile, it comes out at about .65 grams per mile. Even at a 2 gram per test standard, which is being proposed, this still comes out at over .2 gram per mile.

For the diesel, the way we are using it in our production vehicles, we are having a very difficult time even measuring any evaporative emission loss. So, it is really considered negligible. Now, we are using, in effect, a sealed tank with a pressure release cap which does help control what small evap emissions there are.

Thus, the diesel engine has a real total hydrocarbon advantage in meeting the same pair of standards for exhaust hydrocarbon and evap hydrocarbon. The diesel vehicle has a real advantage in a lot lower hydrocarbon emissions.

Refueling emissions are much the same. The diesel can be expected to have much lower refueling emissions. The gasoline engine has been estimated at about .4 gram per mile. The last time this estimate was put together was at a 13.5 mile per gallon average. Of course, the emissions from refueling will go down as the fuel economy of the vehicles goes up because the refueling emissions are essentially equal to a constant grams per gallon refueled. The diesel will be much lower just because of the vapor pressure of the fuel.

Next one, Sam?

In the maladjustment and tampering area, it also looks like the diesel has some major advantages. You can project that there will be definitely a lower probability of any maladjustment of tampering, really, because of a couple of things. There are fewer emission components which can be adjusted. There just are not as many on the diesel engine as there are on the gasoline engine, and the adjustments are really more complex.

Now, that sounds like a disadvantage; but it may be an advantage from the customer's standpoint because he won't be so familiar with them and won't be so inclined to make unreasonable adjustments. The other basic characteristic of the diesel engine is that it operates unthrottled with excess air. So, essentially all of the control of the engine is centralized in the fuel injection system. That becomes the main control. That can preset, precalibrated and more readily sealed during the production of the vehicle. This should have an impact on maladjustment and tampering.

Next one, Sam?

The main area that people have talked about of differences between the gasoline and diesel engine or comparing the two engines has been the energy requirement for the engine.

If you look at the EPA 55/45 numbers, it appears to us that there is about a 25 percent improvement in fuel economy with the diesel engine. In fact, if you compare the Olds 350 diesel with the 260 gasoline, there is about a 28 percent improvement for the diesel. That totals up to a lot of fuel, about 700 gallons of fuel over 100,000 miles.

The other one, which is not as readily apparent, is that our experience with the vehicles so far, with the diesel engine in passenger vehicles, is that you can obtain these fuel economy numbers more readily with the diesel engine than you can with the gasoline engine. You end up operating at or near the EPA composite numbers and the city and highway numbers with the diesel engine than you do with the gasoline engine.

Another area is that the diesel engine does not have any choke enrichment during cold start, so that cold start fuel economy, particularly during short trips in cold weather operation, the diesel shows a major advantage. The only disadvantage area from an energy standpoint is that, with durrent designs, the diesel does require more frequent oil changes. With the Olds 350, we are specifying oil changes at a 3000 mile interval in comparison to the gasoline engine at a 7500 mile interval. That amounts to about an extra 40 gallons of oil during 100,000 miles that the diesel is going to use just in oil changes.

May I have the next one, Sam?

Natural resources is another area where the diesel has significantly less critical materials. There is no catalytic converter.

The catalytic converter, of course, has a significant amount of chromium in the exhaust pipe and the catalyst cannister itself; and, of course, the catalyst has platinum, palladium, and is going to have in future years, rhodium included in the catalyst. None of these critical materials would need to be utilized in the diesel exhaust.

Next one, Sam?

From a reliability standpoint, it appears that the diesel also has some potential advantages. I mentioned before that the control of the engine is really centralized in the fuel system so that the system can be more readily precalibrated. Things like timing and pressure can be preset and installed in the vehicle as a manufactured unit.

One other important thing from a production standpoint is that the diesel, because of the characteristics of the diesel fuel, can be tested at the engine plant with the fuel that it is going to eventually run on. In the case of gasoline, that is very difficult to do because you run into serious problems of trying to ship gasoline engines with some small amount of gasoline in the engine someplace. It is just too much of a hazard to do that.

From the customer's standpoint, the diesel and gasoline are really being designed to be of equal reliability in customer use. However, as I mentioned before, the diesel is going to require, with current designs, more frequent oil changes. There is an open question of whether the customer will really make these more frequent oil changes. If he does not, that can have some detrimental effects to the capability of the diesel engine.

May I have the next one, Sam?

Finallly, we get down to overall customer cost. Based on our current engine designs, the Olds 350 is about $750 more costly on the new car price than the gasoline engine. However, the fuel cost for the Olds 350 is about $890 less over 100,000 miles. If you compare the Olds 350 diesel to the 350 gasoline, this fuel differential gets over $1500 over 100,000 miles.

The maintenance cost is kind of mixed. In ways, it is better, and in ways, it is not. The diesel has fewer maintenance items just because it has fewer components such as emission control components that need to be maintained. The diesel does require more frequent oil changes and, at the same time, filter changes. This does have a significant impact on the maintenance cost of the diesel engine. This area of the diesel engine, the more frequent oil changes, is one of the major development areas that is being pursued. We need to get the oil change interval of the diesel engine to be very comparable to the gasoline engine because this does have a significant impact on the customer acceptance of the vehicle.

Thank you.

(Written papers follow.)

A COMPARISON OF
DIESEL AND GASOLINE ENGINES
FOR
PASSENGER CAR USAGE

GENERAL MOTORS CORPORATION

April 24, 1978

A COMPARISON OF DIESEL AND GASOLINE ENGINES FOR PASSENGER CAR USAGE

This paper compares the diesel and gasoline engines from a wide range of aspects. This comparison is based primarily on the current status of diesel engine development. Therefore, subsequent diesel engine development can be expected to modify this comparison. The following summarizes the comparison of the two engines by subject area.

I. ENVIRONMENTAL

A. GASEOUS EXHAUST EMISSIONS

1980 Standards (.41 HC/7.0 CO/2.0 NOx)

Certification - In order to meet the .41/7.0/2.0 standards, our gasoline engines will probably be equipped with an oxidation converter, Air Injection Reactor (AIR) or PULSAIR, and backpressure exhaust gas recirculation (BPEGR). Some difficulty in meeting the .41 HC standard may occur during the EPA durability schedule. Meeting the 7.0 CO and 2.0 NOx standards should cause little problem during certification.

The .41 HC standard will be difficult for the present Oldsmobile light-duty diesel engine to meet. This present diesel engine has HC emissions of 0.7 to 1.1. Experimental engine designs are showing improved HC emission levels, however.

High Mileage Performance - There is very little information on emission control performance above 50,000 miles. However, one would speculate that engine-out HC and CO emissions from the gasoline engine would probably continue to increase. The AIR or PULSAIR systems will tend to minimize the effects of such increases. If high engine oil consumption occurs after 50,000 miles, catalyst effeciency would tend to be further degraded.

Based on the performance of heavy duty truck diesel engines, one would believe that the emissions from our Oldsmobile diesel engine would probably be stable with mileage after 50,000 miles.

1981 Standards (.41 HC/3.4 CO/1.0 NOx for Gasoline Engines and .41 HC/3.4 CO/1.5 NOx for Diesel Engines)

Certification - This discussion assumes that (1) General Motors will not be able to have the 3.4 CO standard waived to a 7.0 CO standard for many models using the gasoline engine and (2) the 1.5 NOx standard waiver for the diesel engine will be obtained.

In order to meet the .41 HC/3.4 CO/1.0 NOx standards, our gasoline engines will probably be equipped with either (1) a dual bed (3-way plus oxidation) converter, closed-loop carburetor control (CLCC), and AIR or PULSAIR or (2) a 3-way converter, CLCC, AIR (on warm-up) and BPEGR. Achieving the .41 HC/ 3.4 CO/ 1.0 NOx standards will be difficult especially when considering possible deterioration in system performance and manufacturing variation. Rapid warmup of the control system is required to meet the .41 HC and 3.4 CO standards.

In order to meet the 1.5 NOx standard, the Oldsmobile diesel engine will probably have to be equipped with EGR. The use of EGR will tend to increase HC and particulate emissions. Consequently, the .41 HC standard in combination with the 1.5

NOx standard will be quite difficult to achieve.

High Mileage Performance - The remarks on high mileage performance for gasoline engines previously presented continue to apply here. Also, the long-term durability of the diesel engine may be adversely affected by the increased particulate emissions caused by use of EGR. This adverse effect results from additional particulate contamination of the engine oil.

B. EVAPORATIVE EMISSIONS

Diesel fuel has comparatively low volatility - about l psi Reid vapor pressure compared to 9 psi for (emission test) gasoline. Evaporative emissions from diesel vehicles are, therefore, commonly considered to be negligible. During development of their diesel engine, Oldsmobile did perform limited evaporative emission testing of diesel cars, using the SHED technique. Values obtained with the production design were so low that it was not possible to distinguish any evaporative emissions from the nonfuel "background" of the test cars. However, the Oldsmobile production design vents the fuel system only through a tank cap pressure relief valve. Earlier tests with open vent tanks produced l to 2 g/test.

By comparison, today's evaporative emission standard for gasoline cars (6 grams per SHED test) translates to approximately 0.65 g/mi. California has established and EPA has projected a nationwide future evaporative emission standard of 2 g per SHED test which translates into a g/mi value of approximately 0.22. Gasoline cars without evaporative emission control have been estimated to average 4.3 g/mi of evaporative emissions.

Refueling emissions from gasoline cars, on the other hand, were interpreted by a major research project as approximately 0.4 g/mi. The latter, however, was based on then existing U.S. fleet average fuel economy of approximately 13.4 mpg. The present or future gram per mile interpretation of refueling emissions would be proportionately lower as the fleet average fuel economy value rises, since the refueling emissions are essentially a constant gram per gallon refueled value. GM is unaware of any experimental measurement of diesel vehicle refueling emissions. Theory would suggest that diesel refueling emissions should be lower than gasoline by about the ratio of the fuel vapor pressures.

C. PARTICULATE EMISSIONS

1. Control Potential

a. Gasoline Engines

The control of particulates from gasoline engines has been greatly assisted in two ways by the introduction of catalyst emission control systems. First, the requisite removal of lead compounds from gasoline used in catalyst-equipped vehicles has nearly eliminated particulate emissions from 1975 and later model year General Motors vehicles. Lead and lead compound emissions from noncatalyst vehicles are about 0.3 g particulates/mile. Lead levels in the atmosphere should decrease further as the percentage of vehicles using unleaded gasoline continues to rise. Second, high molecular weight organic species, which condense in the atmosphere to particulate matter, appear to be very effectively controlled by catalyst emission control systems.

However, current oxidation catalyst systems do emit some particulates in the form of a sulfuric acid mist. These emission levels are quite low and are not thought to be a problem. Based on simulated high density freeway operation, only very small increase in atmospheric sulfate level resulted. Sulfate emissions will probably be further reduced by operation at the stoichiometric air-fuel ratio, as is required by GM's Phase II catalyst systems.

b. Diesel Engines

Control of particulates is interrelated with control of other diesel exhaust pollutants. In order to meet 1981 standards of 0.41, 3.4, and 1.5 (assuming EPA grants the waiver from 1.0 NOx), EGR must be used to achieve a target of about 1.1 NOx (to allow for production variation and possible field deterioration). Although the use of EGR will increase HC and particulates, the 1981 diesel system particulate level will not be much greater than the 1978 mean of 0.86 g/mile. By comparison, particulate emissions from current GM catalyst vehicles operating on unleaded gasoline are 0.02-0.04 g/mile, essentially all sulfate.

Although the percent fuel sulfur may be an order of magnitude higher in diesel fuel than in gasoline, sulfate emissions from diesel engines are on the order of 0.02 g/mile.

2. Health Significance

a. Gasoline Engines

Trace amounts of about thirty polynuclear aromatic hydrocarbons (PNA's) and at least eight phenols have been identified in gasoline engine exhaust. Of the PNA group, at least ten have been considered carcinogenic, while five of the phenols (which are toxic but not carcinogenic) have been shown to promote tumors in mice even when only very weak carcinogens were present.

Skin tests with concentrated PNA solutions have not demonstrated that these substances play a role in causing cancer in humans. Nevertheless, measures which will decrease PNA emissions--either by the manner in which engines are operated, by fuel composition, or by auxiliary means--should be pursued. However, proof of a causal relationship between general air pollutants and lung cancer requires at least dose-response studies with animals as a minimum. Such studies have not yet been performed.

Any health problem represented by toxic lead compounds from motor vehicles in the ambient air is now thought to be primarily in the past, or at least it should be greatly reduced, as lead is phased out of gasoline.

b. Diesel Engines

Health effects studies of diesel exhaust to date have concentrated on the particulates since they are a more significant factor in diesels than in gasoline engines. It has been speculated that these particulates may be considered harmful for the following reasons: (1) they are generally high molecular weight polycyclic aromatic hydrocarbons (many of which in laboratory experiments with mice and using concentrated amounts, have demonstrated a degree of carcinogenicity); (2) they have high specific surface area, which theoretically enables them to carry adsorbed exhaust gases on their surface; (3) their low settling velocity in air allows time for oxidation and degradation to lower molecular weight compounds (e.g., benzpyrene, benzanthracene), some of which have been shown, in concentrated amounts, to be carcinogenic; and (4) particles are of a size which may penetrate deeply into the lung and may retard the lung's clearance defense mechanism when deposited.

Diesel particulate emissions, although containing trace amounts of carcinogens, have not been shown to produce any significant additional hazard to humans over gasoline engines. Several epidemiological studies of humans exposed to diesel exhaust for long periods confirm this. However, since increased usage of diesels is planned, additional health effect studies are needed.

In work done at the Sloan-Kettering Institute for Cancer Research, diesel "tar" samples taken from a GM 6V-71 diesel engine were used in experiments on mice. These tars, which contained significant amounts of BaP (benz(a)pryene) and BaA (benz(a)anthracene), had very low tumorigenic activity but were not carcinogenic. Results of experiments may vary, however, when other engines, fuels, operating conditions, or methods of biological evaluation are used. In general, particulate tars collected from diesel engines have shown less biological activity per unit mass of tar than have those from gasoline engines or cigarettes.

D. MALADJUSTMENT - TAMPERING

A review of the potential for maladjustment or disabling of emission control systems on passenger car diesel engines compared to gasoline engines indicates that the probability of maladjustment of a diesel engine would be far less than for a gasoline engine.

Current Technology diesel engines have fewer specific emission related components, the potential maladjustments are more complex to accomplish, the adjustment mechanisms are not as readily accessible, and the average passenger car owner is not as familiar with diesel engine operation. In addition, since the engine operates unthrottled with excess air, the engine operation is primarily controlled by the fuel injection calibration and adjustments. These are preset and sealed during manufacture. These conditions, coupled with the fact that some maladjustments of the diesel engine would require the breaking of seals which could void expensive warranty items, tend to discourage maladjustment attempts.

Furthermore, 1980 model year General Motors gasoline engine vehicles will have provisions taken to further limit accessability of adjustment mechanisms.

E. NOISE

The diesel engine is inherently more noisy than its gasoline equivalent due primarily to the spontaneous combustion process. The diesel combustion process excites higher levels of mechanical vibrations resulting in higher levels of engine radiated noise.

Presently, many states and local communities require automobiles to meet an 80 dBA noise level when tested per the Society of Automotive Engineers procedure J986a which is a wide-open throttle passby noise test. To meet the 80 dBA requirement, GM internal guidelines suggest design levels 2 to 3 dBA below the requirement in order to allow for normal production variations. 1978 model year compliance data obtained to date shows the diesel engine Oldsmobile to be comparable to the gasoline engine

Oldsmobile (76.5 dBA for diesel and 76.6 dBA for gasoline) when tested per SAE J986a.

A wide-open throttle test is not realistic when compared to the way vehicles are operated in the community. Both General Motors and the Environmental Protection Agency (EPA) have been studying an "urban acceleration" noise test procedure which more closely simulates community driving situations. Tests performed by the EPA using their procedures show the level of the diesel to be 6 dBA higher than the gasoline equivalent. Other diesels were found to be similar in noise level to the GM diesel.

In anticipation of Federal regulation of passenger cars and light trucks, General Motors initiated a Noise Reduction-Hardware/Cost Study which included an Oldsmobile diesel-equipped passenger car. Using a GM proposed urban acceleration noise test, similar but not identical to the procedure proposed by EPA, it was determined that a 4 dB reduction in urban acceleration noise level would result in a $26 customer cost increase for the diesel-powered vehicle. The modified diesel vehicle still has a noise level of 3.6 dBA above the production gasoline engine powered vehicle.

A 1978 production diesel engine Delta 88 Oldsmobile gets the following extra noise-reducing treatment: dash mats (front of dash), double thickness underhood insulation and additional body treatment. This adds $45.82 (quoted as Oldsmobile cost) above that of an equivalent gasoline engine Delta 88 Oldsmobile and is reflected in the diesel option cost.

Noise control treatment of vehicles is necessarily designed to have no adverse effect on fuel economy or emissions in a direct sense, e.g., engine back pressure should not be allowed to increase with additional exhaust noise control. However, the added weight due to barriers, mats, insulation and larger silencers cannot be ignored as a fuel economy factor when assessing diesel versus gasoline engines.

II. SAFETY

A. POTENTIAL FOR VEHICLE FIRES

Diesel fuel, when compared to gasoline as an engine fuel, can produce both a positive and negative contribution to the prevention of vehicular transportation fires. Due to specific differences in physical/chemical attributes, the conditions surrounding the spillage or release of the fuel play a major role in determining the relative potential of the fuels to ignite.

There are generally six broad classes of conditions which may create the circumstances that can result in ignition of accidentally spilled fuel.

1. Engine compartment leakage from fuel metering devices or supply lines during or prior to engine operation.
2. Fuel storage tank or fuel supply system loss of integrity during vehicular collisions.
3. Vehicle refueling operation.
4. Fuel storage system service and repair.
5. Bulk fuel transporation as part of the marketing/ distribution system.

6. Bulk storage either at the retail or wholesale level.

There are two principal differences (spark and hot surface ignition characteristic) between diesel fuel and gasoline, which, individually or in combination, contribute to the propensity of the fuels to ignite under the various conditions above.

Volatility is the measure of the fluid's ability to change from a liquid state to a vapor state under a given set of ambient conditions. Since a higher volatility fluid has the greater ability for its vapor to mix with the surrounding air to create a combustible air/fuel mixture at normal temperature, gasoline has historically been considered the easier to ignite or more hazardous fuel. Such is far from always being the case.

One common relative measure of volatility used to describe differences between combustible fluid is their flash point.

The flash point is defined as that temperature at which sufficient vapor will be released or evaporate to mix with air so that an external ignitor (spark or open flame) will initiate a propagating or continuing flame independent of the ignitor. Typical gasoline has a flash point of minus 45 degrees Fahrenheit (-45°F), while diesel No. 1 and 2 fuels have flash points of one-hundred and one-hundred-twenty degrees Fahrenheit (100°F and 120°F), respectively.

Based on flash point, gasoline vapor may be ignitible if fuel leakage occurs during cold engine start-up in the presence of deteriorated high voltage ignition wires, high energy spark discharge of the starter system, loose high voltage connections, or if an ignitible air/vapor mixture finds its way into the center of the engine distributor. Diesel fuel is generally not considered ignitible under these conditions. Similarly, refueling or service operations accompanied by careless use of smoking materials or unprotected electrical tools may create a hazard with gasoline vapor but not usually with diesel fuel at normal temperatures (below 100°F). However, if the smoking material or spark can raise a portion of the spilled diesel oil to a temperature above its flash point and still remain hot enough for ignition, a propagating fire can ensue.

Another common relative measure associated with volatility is the liquid's boiling point. The boiling point can be defined as that temperature at which the gas pressure of the escaping vapor is equal to or very slightly greater than the surrounding atmosphere. At this point large amounts of vapor will be released quickly, limited only by the heat capacity of the source to deliver energy to the liquid. Practical volatility differences between the two fuels largely disappears because both gasoline (with a variable boiling point ranging from 100° to 400°F), and diesel No. 1 and 2 (with a boiling point of 350° to 530°F), can produce sufficient clouds of ignitible air/vapor mixture at 500°F and above. This temperature can be exceeded by the exhaust components on an operating engine.

Two situations that may produce ignition of vapor exist at this temperature range. The first, spark ignition, is largely independent of the factors influencing gasoline or diesel fuel ignition at lower temperatures and their propensity to ignite can be considered essentially equal with high energy sparks and large vapor clouds. The second situation, hot surface ignition on hot exhaust components, creates grossly different results between the two fluids with diesel fuel marginally ignitible around 500°F but readily ignitible in the 900-1000°F range. Gasoline under the same conditions, does not normally ignite on a hot surface in the engine compartment below 1500°F surface temperature. This difference is created by the much higher gasoline vapor pressure (volatility factor) causing ignitible mixtures of air and vapor to occur at a greater distance above the hot surface. This requires very high initial vapor temperatures to be maintained longer in the presence of the cool in-rushing air to arrive at a proper mixture at or above the mixture's ignition temperature. Diesel fuel vapors are significantly less active due to lower vapor pressure and incoming cool air is able to more readily reach the hot surface to be warmed concurrently with the diesel vapors.

During vehicular collision, where the frontal area of one or both vehicles is commonly involved, the escape of diesel fuel poses an ignition possibility primarily based on the operating temperatures of the engine compartment components and secondarily based on spark or flame ignition. Gasoline has the greater ability to be ignited by stray sparks from the battery, electrical ignition components, and hot filaments of broken lights. A measure of this is the fact that the vast majority of post collision vehicular fires occur in the engine compartment even though the fuel system crash integrity has effectively been maintained. Undoubtedly, these engine compartment fires are largely being generated by escaping oils and other hydrocarbon based fluids coming in contact with hot exhaust or electrical components.

The bulk fuel transportation industry has historically become involved in dramatic and sometimes catastrophic fires at the bulk dispensing center, during in-transit vehicular accidents, or at the retailer/receiver location. In general, excluding unpredictable equipment malfunction and overheat, gasoline can be considered more hazardous during either the loading or unloading phase for two reasons:

1. The gasoline vapors available at temperatures below 100°F are significantly greater; therefore, they can become available to ignitors more frequently and for greater distances.

2. The initial ignition stage can involve much wider areas faster with gasoline, placing a higher premium on positive, early fire suppression measures.

These statements are applicable to environments below 100 to 120°F. Climatic or industrial operational circumstances causing temperatures at or above this range could eliminate the initial advantages diesel fuel may offer.

With regard to vehicular accidents involving large bulk carriers, special emphasis has singled out gasoline as a particularly hazardous substance while ignoring the somewhat similar ignitibility of diesel fuel.

III. ENERGY

From an energy consumption standpoint the diesel engine shows definite advantages over the gasoline engine. In evaluating energy consumption comparisons, it should be noted that diesel fuel has more energy (Btu) per gallon -about 11% for No. 1 diesel and 14% for No. 2 diesel. Since it is indeterminate at this time whether this energy content difference will be reflected in actual crude oil quantity required for the fuels, the following discussion of energy consumption is based on the gallons of fuel consumed.

The diesel engine provides improvement in fuel economy of at least 25% at comparable performance levels. The current Olds 350 diesel shows a 28% improvement over the Olds 260 gasoline. This fuel economy improvement is expected to be more easily realized in actual customer service based on our test data. For example, on a test trip between Lansing and Denver, the Olds 350 diesel engine showed about 30% higher fuel economy than the Olds 260 engine. On that trip the diesel engine vehicle achieved 25 mpg - more than the EPA composite fuel economy of 24 mpg. The Olds 260 gasoline engine vehicle just equaled the EPA composite level of 19 mpg. Thus, there is some support for the belief that the diesel engine vehicle will more readily achieve the EPA levels than will the gasoline engine vehicle.

During cold start operation, the diesel engine also shows a fuel economy advantage. Since the diesel does not require mixture enrichment when cold (choke on the gasoline engine), the operation period of the diesel during which the gasoline engine choke is closed shows large fuel economy improvement. The impact of this on total actual vehicle fuel economy, of course, will depend on the amount of cold start operation actually encountered.

On the basis of total energy consumed, the diesel engine shows substantial advantage over the gasoline engine. For example, the Olds 350 diesel uses about 700 gallons less fuel during 100,000 miles than the Olds 260 gasoline and over 1200 gallons less fuel than the Olds 350 gasoline. However, the diesel engine uses more lubricating oil during 100,000 miles than the gasoline engine At current oil change intervals (3,000 mi for diesel and 7,500 mi for gasoline) the diesel uses about 40 gallons more lubricating oil. Even with the higher use of lubricating oil, the diesel engine results in sizable savings in petroleum consumption. Development programs are underway to extend the diesel oil change interval thru improvements in engine design and improvements in the lubricating oil.

IV. NATURAL RESOURCES - CRITICAL MATERIALS

The diesel engine, when installed in a vehicle with emission control systems needed to meet the standards, requires significantly less critical materials than the gasoline engine. This results primarily from the necessity of the gasoline engine to be equipped with an exhaust catalytic converter for emission control. Since this is not required for the diesel engine, the converter system's content of nickel, chromium, platinum, paladium and rhodium in the exhaust pipe, canister and catalyst are not required. Most of the chromium used in the gasoline engine vehicle is in the catalytic converter canister and the exhaust pipe of the engine. Only the stainless steel intake valves and larger size radiator, including the integral oil cooler of the diesel engine, are areas where the diesel requires marginally higher use of critical materials such as nickel, chromium and copper. In total, however, the diesel engine uses much lower quantities of critical materials.

V. RELIABILITY

Review of reliability in terms of the probability of manufacturing and assembling a properly functioning vehicle shows some definite advantages for the diesel engine. First, since the diesel engine operates unthrottled with excess air, the control of the engine is centralized into the fuel metering system. This reduces the number of critical adjustments compared to the gasoline engine. Secondly, the diesel engine adjustments such as timing, injection pressure, etc. can be preset or pre-calibrated at the fuel injection system vendor's plant. Thus, the fuel metering and ignition systems reach engine assembly more as pre-adjusted packages than with the gasoline engine. Mechanical assembly of components on the diesel engine is straight forward. Even for the critical area of injection timing of the diesel engine, the engine and pump are individually calibrated, pre-marked and need only to be physically aligned and fastened.

For final engine inspection at the engine assembly plant, the diesel engine is run on actual fuel and shipped "wet" with some fuel in them. Gasoline fueled engines are much more difficult to inspect and ship in this fashion because of the fuel hazards with gasoline.

Thus, even though the diesel engine includes complex fuel handling and metering systems, these systems lend themselves to component pre-calibration more readily than the gasoline engine systems. Use of such pre-calibration approaches can allow improvements in production reliability and quality.

Reliability of the current Olds diesel engine in customer service is believed to be at least equal to the gasoline engine. However, the current diesel engine reliability is very dependent on more frequent oil and filter changes. Whether "normal" customers will actually perform this added service is a very important but, as yet, unanswered question.

VI. SERVICEABILITY

The following are some comments relative to the maintenance and service of the current production Oldsmobile light duty diesel engine compared to gasoline engines.

Maintenance

Scheduled maintenance for the diesel is much simpler than for comparable gasoline engines. The emissions maintenance schedule for the diesel contains only four items compared to as many as eighteen items on gasoline engines. Unfortunately, maintenance cost figures do not reflect this improvement because of the diesel's more frequent oil and filter changes (3,000 miles) and its larger oil pan (7 qts.). All other maintenance is significantly less due to the absence of carburetion and ignition systems.

Unrelated to the cost of regular maintenance, but tied to the cost and convenience of operation, is the engine heater needed for very low temperature starts. Use of the heater is recommended for cold starts below -10°F for the current Olds 350 diesel engine. Use of the heater will result in a small cost for the electricity consumed. Convenience is also involved since electrical outlets may not be readily available when parking for extended periods in extreme cold.

Parts

The diesel offers advantages with unscheduled maintenance. There are no carburetion or ignition systems. These two systems account for the bulk of unscheduled maintenance problems in gasoline engines. On the negative side, the injector pump is more costly and complex to service than the carburetor and ignition system. However, there is reason to believe it can perform satisfactorily.

The diesel engine cranking system with larger capacity battery and starter system will be more expensive to service, but its reliability should be comparable to gasoline engine systems.

The larger Delcotron generator on the diesel will be more expensive to repair or replace.

The diesel vehicle radiator with its integral engine oil cooler will be more costly to repair or replace following collision damage or normal deterioration.

The Hydro-Boost brake system on the diesel vehicle will also be more costly to repair. However, it is a highly reliable system, and very few problems are anticipated.

Labor

The labor times to perform typical operations on the diesel are similar to times for comparable operations on gasoline engines.

VII. CUSTOMER COST

Review of customer cost aspects of the diesel vs. gasoline engine comparison shows different advantages depending on the area of cost. On the basis of first cost, the diesel engine is more costly than the gasoline engine. The Olds diesel additional customer cost is $750 in the Olds 88 and $740 in the Olds 98 over the respective basic V8 engine. For fuel costs, however, the diesel engine shows sizable advantage. At current price levels, fuel cost for the Olds 350 diesel is $24.69 per 1,000 miles in comparison to $33.65 per 1,000 miles for the Olds 88 with the 260 gasoline engine and to $40.00 per 1,000 miles for the Olds 98 with the 350 gasoline engine. Thus, the diesel engine provides a 27% to 38% reduction in fuel cost to the customer.

Total maintenance cost is higher for the diesel engine primarily because of the diesel engine's higher frequency of oil and filter changes; however, other engine maintenance is less frequent for the diesel engine. Over 100,000 miles, the Olds 350 diesel maintenance would cost $527 more than the Olds 260 or 350 gasoline maintenance. This is an offsetting cost against the fuel cost savings of the diesel engine discussed above.

In summary, the comparison of customer cost between the diesel engine and the gasoline engine is mixed based on the existing Oldsmobile engines. For the Olds 88, the total 100,00 mile customer cost is higher for the diesel engine by $381 compared to the standard 260 CID gasoline engine. However, for the Olds 98, the total 100,000 mile customer cost is lower for the diesel engine by $264 compared to the standard 350 CID gasoline engine. Both the higher additional first cost and the more frequent oil and filter changes have major impact on these cost comparisons. Since these estimates are based on the current 1978 engine, engineering improvements can be expected to have beneficial impact on first cost and oil and filter change cost of the diesel in future years, with resulting impact on the comparison.

VIII. CUSTOMER ACCEPTANCE

Overall customer acceptance of diesel engines produced in high volume as alternatives to existing gasoline engines is difficult to gauge. No history exists on such a situation. Currently available diesel engines are available in limited volume. Therefore, the response of current diesel engine owners may not be indicative of the overall customer acceptance of diesel engines for the variety of vehicles.

Based on existing diesel owner (non-GM) comments, the predominate reasons for purchasing the diesel engine were overall operating economy, fuel economy, and engineering aspects. Other aspects such as startability, smoke, odor, and first cost do not appear to their owners as significant differences between diesel engine and gasoline engine vehicles. Only diesel engine noise was rated a disadvantage, if it is assumed that the acceleration potential of the two engines is comparable. However, these survey results may be totally misleading since the current diesel engine owners' reasons for purchase may be very different from the "typical" vehicle purchaser.

More information on this subject will become available in the near future. Oldsmobile has started a survey of diesel owner reaction and other market study groups have expanded studies of the diesel engine acceptance.

CJE/frg/m/255
4/24/78

STATUS REPORT

DIESEL PARTICULATE EMISSION CONTROL TECHNOLOGY

NHTSA DIESEL PARTICULATE EMISSION WORKSHOP
Washington, D.C.
April 27-28, 1978

GENERAL MOTORS CORPORATION

GM Status Report
Diesel Particulate Emission Control Technology

NHTSA Diesel Particulate Workshop
April 27-28, 1978

Introduction

With the Increasing concern for energy conservation, the potential for increased usage of diesel engines in a wide variety of transportation usage is becoming more apparent. In concert with these opportunities, GM is tentatively planning to use diesel engines extensively in passenger cars and light duty trucks and has therefore intentisied its on-going programs to investigate control of particulate emissions, among others. This report describes the status of the diesel particulate control technology program as it stands today.

Chart 1 - Diesel Particulate Emissions

This chart will outline our reasons for concern, measure typical diesel particulate levels measured at our facilities, and describe the efforts of GM's Engineering Staff to reduce particulate emissions.

Diesel engines offer an improvement in fuel economy for passenger cars of approximately 25%. Because of this, GM is planning on using increasing numbers of diesel engines in our future passenger cars and light duty trucks. In contemplating such plans, GM made an extensive review of the medical literature and, based on available information, determined that diesel particulate emissions appeared to cause little or no health problems. A more extensive review of this subject is contained in another GM report presented at this workshop. However, to minimize any potential problem with diesel particulate emissions, GM has increased its efforts to develop improved control measures for diesel particulates.

CHART 1

DIESEL
PARTICULATE EMISSIONS

- PARTICULATES - WHY IMPORTANT
- TYPICAL EMISSION LEVELS
- PARTICULATES PROGRAM
  - APPROACH
  - PROGRESS

Chart 2 - Why Important

A diesel passenger car emits roughly the same particulate mass as a gasoline passenger car run on leaded fuel, or about 10 to 30 times that from a passenger car running on unleaded fuel with a catalytic converter. Besides any potential health problems, as mentioned previously, particulates do contaminate the engine oil and if the oil is not changed regularly, they can contribute to engine wear. Also, government regulation is required by the 1981 model year. If such standards are set too low, these could preclude future production of the diesel unless some effective particulate control measures can be developed.

CHART 2

DIESEL PARTICULATES

WHY IMPORTANT?

- HIGH QUANTITY EMITTED
- AESTHETIC PROBLEM
- POSSIBLE HEALTH EFFECTS
- CONTAMINATE ENGINE OIL
- GOVERNMENT REGULATION

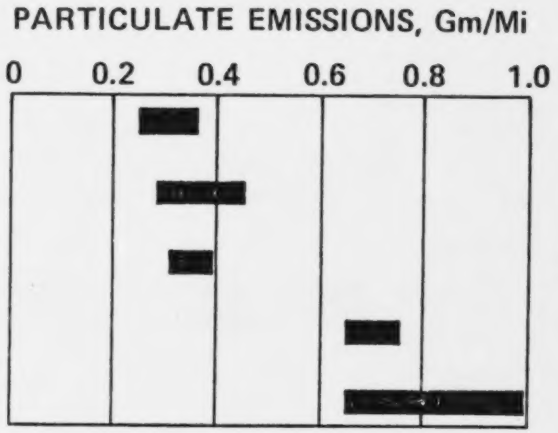
Chart 3 - Description of Particulates

Sooty particulates result from the inhomogeneous, diffusion limited combustion process inherent to the diesel engine. The particulates are tiny agglomerates in the sub-micron range. These are coated with condensed oils. They are found to have a very low bulk density.

CHART 4

PASSENGER CAR PARTICULATE EMISSIONS
1975 FEDERAL TEST PROCEDURE

DIESEL CAR	ENGINE DISPL	TEST WT
A	1.5L	2250 LB
B	2.1L	3000 LB
C	2.1L	3000 LB
D	3.0L	4000 LB
E	5.7L	4500 LB



GASOLINE

PREREGULATION, LEADED FUEL

CURRENT PROD., NO LEAD & CONV.

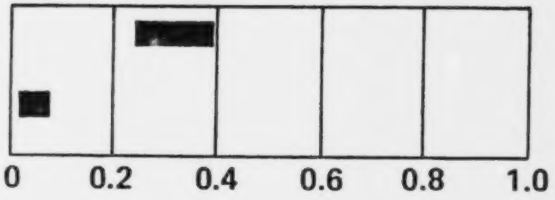


Chart 5 - Diesel Particulates Program

Our program at General Motors started several years ago. Its objective has been to reduce particulate emissions without losing the diesel's advantages.

The first task of the program is to develop measurement methods. The other tasks are three basic approaches to the solution: engine modification, fuel modification and exhaust treatment.

CHART 3

DESCRIPTION OF PARTICULATES

- PRIMARILY SOOT (75 + % CARBON)
- VERY SMALL AGGLOMERATES ($D < 1\ \mu$MET)
- COATED WITH OILS
- LOW BULK DENSITY ($P \simeq 0.075\ \frac{GM}{CM^3}$)

Chart 4 – Passenger Car Particulate Emissions

This chart shows typical particulate emission rates measured on the Federal Urban Test Cycle at our Engineering Staff. There is some question as to the absolute accuracy with these measurements and these numbers may be about 10-15% low. The measured average rates range from about 0.28 g/mi for the smallest car to about 0.85 g/mi for the largest. This is about the range of our cars when they used leaded fuel, however, our current cars using unleaded fuel and catalytic converters are much lower – in the range of .03 g/mi.

CHART 5

DIESEL
PARTICULATES PROGRAM

OBJECTIVES: ACHIEVE SUBSTANTIAL REDUCTION OF DIESEL PARTICULATE EMISSIONS BY PRACTICAL METHODS

PROGRAM:

TASK 1: PARTICULATE MEASUREMENT

TASK 2: DECREASE EMISSIONS BY ENGINE MODIFICATION

TASK 3: DECREASE EMISSIONS BY FUEL MODIFICATION

TASK 4: REMOVE PARTICULATES FROM EXHAUST GAS

Chart 6 – Task 1: Particulate Measurement

Measurement of emission rates and particulate properties is necessary to evaluate and understand progress from reduction techniques. We use constant volume sampler tunnels for mass measurement, an electric aerosol analyzer for size measurement, and several types of smoke meters. Also a number of compositional analyses of particulate samples are conducted.

CHART 6

TASK 1:
PARTICULATE MEASUREMENT

- MASS - CVS TUNNELS
- SIZE - ELECTRIC AEROSOL ANALYZER
- SMOKE - BOSCH SPOTMETER AND ON LINE SMOKEMETERS
- COMPOSITION - ANALYTICAL CHEMISTRY

Chart 7 – CVS Particulate Tunnel

Constant volume sampling tunnels designed for particulate measurement are installed on both chassis and engine dynamometers at Engineering Staff. These tunnels are schematically similar to tunnels used at several other laboratories although somewhat smaller. They are used routinely and give quite repeatable results.

CHART 8

TASK 2:
ENGINE MODIFICATION

- EQUIPMENT
    - SINGLE CYLINDER TESTS OF MODIFIED PRODUCTION ENGINES
    - SPECIAL FUEL INJECTION EQUIPMENT
- APPROACHES
    - IMPROVE AIR/FUEL MIXTURE PREPARATION
    - CONTROL COMBUSTION
    - OPTIMIZE CHAMBER WALL TEMPERATURE

Chart 9 - Task 2: Items Evaluated

A large number of tests have been run involving over a hundred configurations. We have evaluated a great number of alternative combustion chamber designs. We have tested with the flexibility afforded by our fuel bench a great many injector designs and orientations and injection parameters. None of the effort has been successful in lowering particulates significantly except at isolated operating conditions. A number of ways have been found to increase particulate emissions. Although discouraging, this is perhaps not surprising, as low smoke was a primary objective in the development of the passenger car diesel combustion system.

CHART 7

FULL DILUTION PARTICULATE MEASUREMENT TUNNEL
Clayton Dynamometer

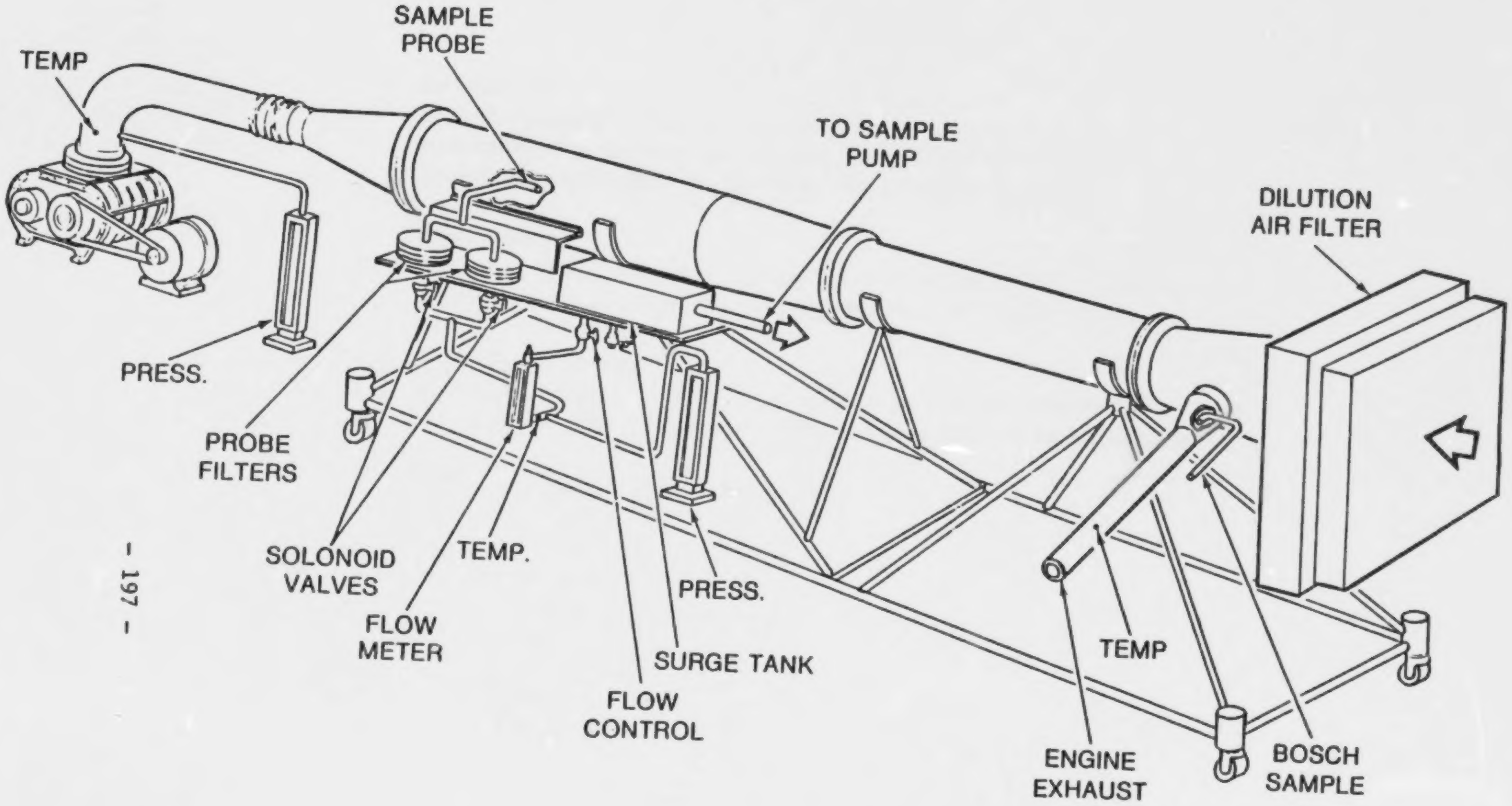


Chart 8 - Task 2: Engine Modification

The work on Task 2 involves single cylinder tests of modified production engines. The Opel 2.1 litre engine has been used in most work to date.

A special fuel injection bench together with special injectors and fuel control are used. These allow variation of all injection parameters.

The general objectives of this task are to effect particulate production by improving the air/fuel mixing process or by controlling combustion rates or optimizing the chamber wall temperature.

CHART 9

TASK 2:
ITEMS EVALUATED

- COMBUSTION CHAMBER
  - SHAPE
  - INSULATION
  - HOT BAR
- INJECTOR CHARACTERISTICS
  - TYPE (PINTLE, HOLE, POPPET)
  - LOCATION
  - SPRAY ORIENTATION
  - ORIFICE PARAMETERS
  - RATE OF NEEDLE LIFT
- INJECTION PARAMETERS
  - TIMING
  - PRESSURE
  - DURATION
  - PULSE SHAPE

Chart 10 - Task 3: Decrease Emissions by Fuel Modification

The third task evaluates various fuel modifications. Several fuel and additive companies have contributed to this effort.

There are at least four basic ways that fuel modification might reduce particulates. If particular hydrocarbon classes are primary causes, their removal within refinery limitations might help. Additives might inhibit reforming or catalyze carbon combustion. Some effects might be primarily mechanical, serving to improve mixing and atomization.

Several approaches are being evaluated in attempts to obtain these effects. These include alternate fuel blends, fuel additives, emulsions and preheating of the fuel.

Some very detailed studies of particulate sources by radioactive tagging of constituents of the fuel and oil is also being done.

CHART 10

TASK 3:
DECREASE EMISSIONS BY FUEL MODIFICATION

- WORK WITH FUEL AND ADDITIVE COMPANIES
- POSSIBLE EFFECTS
  - CHANGE BULK PROPERTIES
  - INHIBIT REFORMING
  - CATALYZE CARBON COMBUSTION
  - IMPROVE ATOMIZATION AND MIXING
- APPROACHES
  - ALTERNATE FUEL BLENDS
  - FUEL ADDITIVES
  - WATER-IN-OIL EMULSIONS
  - FUEL HEATING
- STUDY OF PARTICULATE SOURCES
  - CARBON-14 FUEL TRACERS
  - CARBON-14 LUBRICANT TRACERS

Chart 11 - Effect of Fuel Type

An example of the effect of fuel is shown by comparing particulate emissions with Number 2 diesel fuel and kerosene. The fuel change increased smoke and oxides of nitrogen emissions. However, particulate emissions were much lower on kerosene fuel. The differences are believed due to the combined effects of increased volatility, and lower aromatics.

CHART 12

EFFECT OF ADDITIVES ON DIESEL ENGINE PARTICULATES

4-CYLINDER 2.1 LITER ENGINE
DYNAMOMETER DATA EXCEPT WHERE NOTED

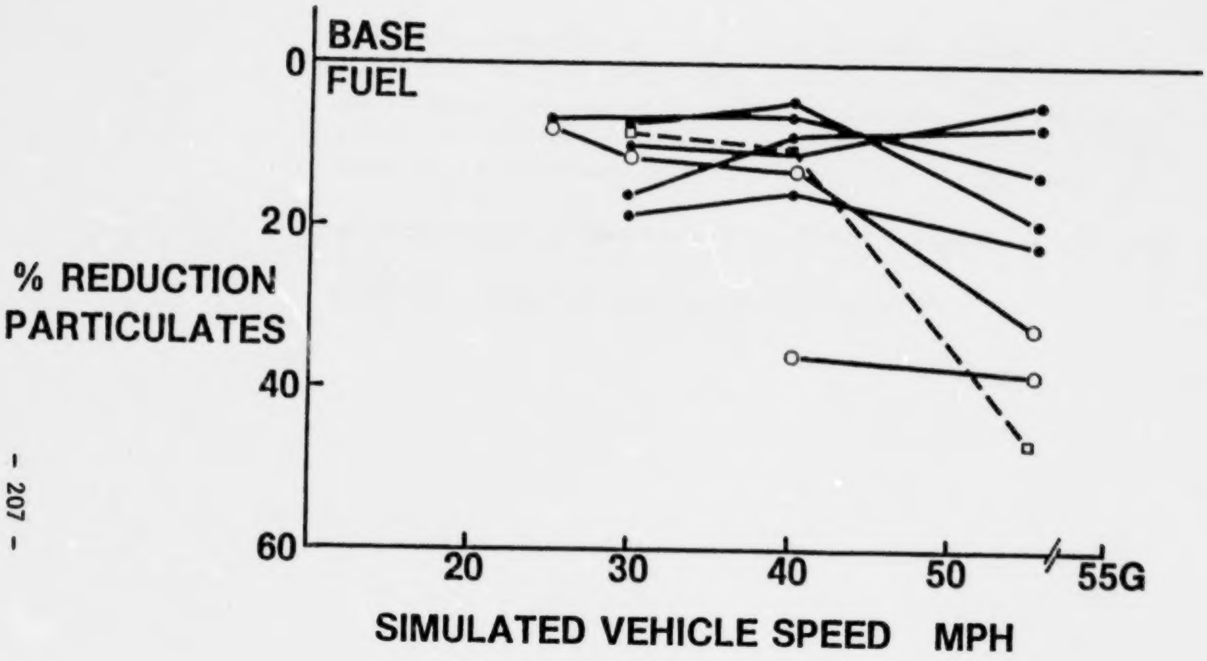


Chart 13 - Fuel and Additive Studies - Summary

A brief summary of results of the fuel studies is shown in this chart.

None of the improvements appear sufficient to warrant general use except the alternate blends. It is doubtful that these are available for widespread automotive application. Further, we are not finding these same levels of improvement as we begin applying some of our Opel engine background to the new Oldsmobile engine.

CHART 11

KEROSENE VS D-2 FUEL

OPEL 2.1ℓ ENGINE 2000 RPM

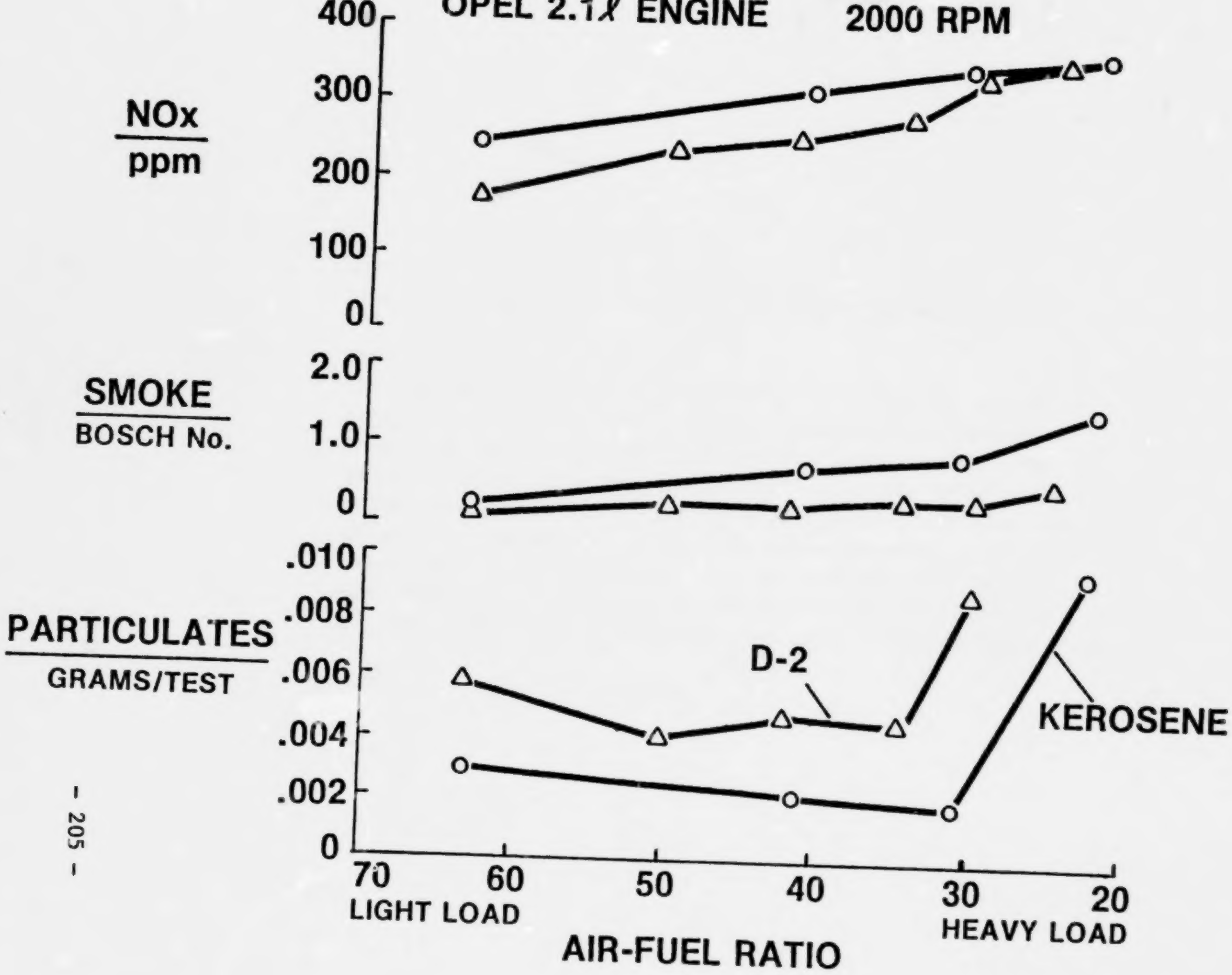


Chart 12 - Effect of Additives

A great number of fuel additives have been evaluated which have been suggested and provided by our fuels & lubricant Research personnel, additive companies, and oil company research & development personnel. Some have shown decreases in particulates, others have had no effect, and some have given large increases - often accompanied by smoke reduction. This plot shows those that have given some indication of particulate improvement in our preliminary screening test. In this dynamometer test they have demonstrated from 10% to 50% reductions at a single engine operating point.

The best of these have then been car tested where improvements of from 5% to 15% have resulted.

CHART 13

FUEL AND ADDITIVE STUDIES
SUMMARY OF RESULTS TO DATE

	OPEL DIESEL TYPICAL PARTICULATE REDUCTIONS		OLDS DIESEL VERY PRELIMINARY
	DYNOMETER TESTS	VEHICLE TESTS	DYNOMETER TESTS
ADDITIVES:			
TYPE A – SPEEDS IGNITION	15%	5%	< 5%
TYPE B – CATALYZES CARBON	15%	15%	5%
TYPE C – IMPROVES DISPERSION	–	–	< 5%
EMULSIONS:			
SURFACTANT	10 – 20%	7%	0 – 15%
NON-SURFACTANT	–	–	–
FUEL BLENDS:			
D – 1 –	30%	–	–
KEROSENE	40%	–	–
LOW AROMATIC	37%	–	10 – 30%
HEATED FUELS:			
DIESEL #2 @ 260°F	11%	–	–

Chart 14 - Remove Particulates from Exhaust

The fourth task is to develop practical methods of removing particulates from the exhaust gas. This is not the most desirable method as it does not alleviate the engine oil contamination problem, and requires add-on hardware with resultant weight, size and cost penalties. Nonetheless, it has received increasing emphasis as the difficulty of solving the problem in the combustion process by modifying the engine or by fuel change becomes apparent.

A number of approaches to exhaust cleanup have been considered.

The particles are much too small to be removed by centrifuges.

Water scrubbers appear impractical for passenger cars, although they might be applicable to some commercial vehicles which could be serviced every few hours.

Some work has been done on electrostatic concentration of particulates. Results were relatively poor and inconsistent. The electrostatic approach appears impractical in motor vehicles.

Oil bath filters are moderately effective in removing particulates but add tremendously to hydrocarbon emissions. Also oil replacement and disposal would present major problems and costs.

Such exotic concepts as molten salt baths have been considered but appear impractical in most motor vehicles.

Passive trapping appears to be the only practical approach. GM effort is concentrated in this area. Disposable traps appear to have limited potential at current emission levels because of the low bulk density of the particulate. A relatively clean car (0.3 g/mi) emits approximately one gallon of particulates per thousand miles. However, this is the simplest solution and could become increasingly practical as cars get smaller and if some progress is made in the combustion and fuels areas. At present it appears necessary to trap and store temporarily until trap loadup requires regeneration of the trap.

Because of the very small size of the particulates ($\bar{D} \simeq 0.1$ μmet) the primary trapping mechanisms are diffusion and electrostatic attachment. For these to be effective the trap material must have a very high ratio of surface area to volume. The required properties of a trapping material are high efficiency, high capacity, and low pressure drop.

CHART 14

TASK 4.
REMOVE PARTICULATE FROM EXHAUST

- CENTRIFUGE

  PARTICLES TOO SMALL FOR DYNAMIC REMOVAL

- WATER SCRUBBER

  HIGH WATER CONSUMPTION AND DISPOSAL PROBLEM
  IMPRACTICAL FOR MOST MOTOR VEHICLES

- ELECTRICAL PRECIPITATION

  ERRATIC PERFORMANCE
  REMOVAL AND DISPOSAL UNSOLVED

- OIL BATH

  LOW EFFICIENCY
  INCREASES HC EMISSIONS
  OIL REPLACEMENT AND DISPOSAL PROBLEMS

- MOLTEN SALT

  IMPRACTICAL IN PASSENGER CAR

- DISPOSABLE TRAP

  HIGH EFFICIENCY
  PRACTICAL IN FUTURE

- TRAP WITH PERIODIC REGENERATION

  BEST APPROACH AT CURRENT EMISSION LEVELS
  PRACTICAL REGENERATION DIFFICULT

Chart 15 - Electron Micro-graph of Mesh Material

This chart is an electron micrograph of one such material showing the highly porous coating as well as the very large pores. This material achieves efficiency of the order of 50% and good relatively slow back pressure buildup.

CHART 16

UNDERFLOOR "MESH" PARTICULATE TRAP

1976 OPEL REKORD - AUTO. TRANS.

	STD. CAR	1 TRAP	2 TRAPS	+ .25 GM/GAL Mn FUEL ADDITIVE
MILES ON TRAP AT START				
MUFFLER	–	18	535	740
RESONATOR	–	–	185	390
				SOME STAINLESS STEEL MESH DETERIORATION
1975 FTP				
PARTICULATE $\frac{GM}{MI}$	.298	.153	.127	.098
HC $\frac{GM}{MI}$	.457	.295	.318	.303
(TRAPS HAD NO EFFECT ON CO, NOx, MPG)				
EXH. PRESS, 40 RL IN. H_2O	18	16	32	50+
EXTER. NOISE, 30 RL DB	72	71	71	71

Chart 17 - Summary

As a final summary of GM progress, active particulate reduction activities are on-going in both Divisions and Staffs at GM.

We now realize that it will be very difficult to lower particulate emissions much below the levels attained in current highly developed engines except by trapping. Further, it is apparent that the development of a practical and reliable trap system will require a major engineering effort and success cannot be assured at this time.

CHART 15

TRAPPING

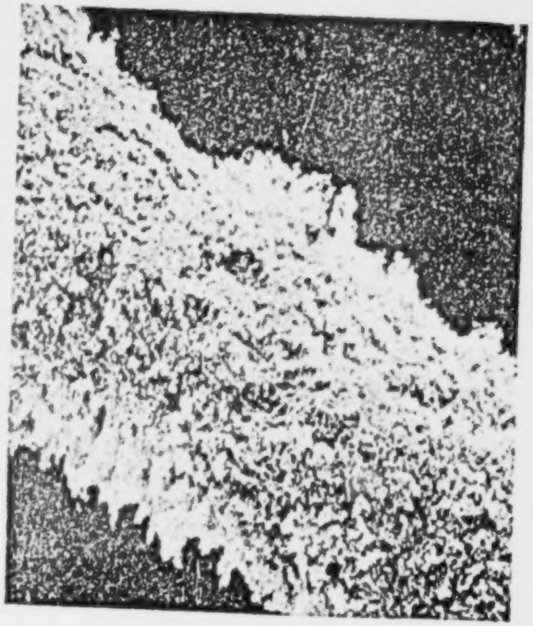
Collection in depth by attraction to open matrix of particules apparently changed in engine combustion

"BRILLO" MESH SAMPLES

10x MAGNIFIED

→||←100 MICRONS

100x MAGNIEFIED



→||←10 MICRONS

HUMAN HAIR - 50 MICRONS (.002 IN)

Chart 16 - Mesh Trap Performance

This chart shows typical trap performance on an Opel Rekord vehicle. The three columns show performance with a muffler trap only, with both muffler and resonator traps, and finally with these plus fuel with manganese added. Nominally 50% particulate reduction was achieved with the single trap on the Urban test cycle. With both traps and the special fuel, a 2/3 reduction was achieved. It should be noted that about 30% HC reduction was also achieved. Noise was essentially unaffected.

After about 700 miles, the trap was loaded and the back pressure was rising rapidly. This is obviously an impractically short service interval. A satisfactory method of trap regeneration must be developed.

Trap regeneration after removal from the vehicle could be accomplished rather easily by incineration or other methods. However, we believe this is an impractical requirement for a passenger car or even for most commercial vehicles. For this reason a considerable effort is being applied to conceive and develop practical methods for in-situ regeneration.

The diesel particulates problem is also closely related to the NO_x control problem. The most effective method of reducing NO_x on the diesel is exhaust gas recirculation. Unfortunately, the use of EGR increases particulate emissions. This is a full subject by itself and therefore will not be elaborated on here.

CHART 17

SUMMARY

- EXPERIMENTAL PROGRAMS ARE IN PROGRESS
  - CAR DIVISIONS
  - CORPORATE STAFFS
  - COMPONENT DIVISIONS
- SMALL REDUCTIONS DEMONSTRATED IN SOME ENGINES USING ADDITIVES
- UP TO 50% CLEANUP DEMONSTRATED WITH TRAPS FOR LIMITED PERIODS
- NO PRACTICAL SYSTEM YET DEVELOPED

MR. HURN: Thank you Chuck, for an excellent review of differences as you might see them. I think we all look with keen anticipation to see what the customers do in acceptance of the diesel.

We move along to the next presentation, then; and we come to the real focus of this afternoon's presentation, "Control Technology for Diesels," and to tell us how he sees this generally, John Johnson, whom you heard this morning.

PROF. JOHNSON: The problem of control, obviously, is a very complex problem. As you know, this morning, we got into a lot of discussion and concluded that we really did not know precisely, from an atmospheric and from a health aspect, exactly what we were really ultimately chasing. So, three years ago, because of the problems of measurement, in our own research we have really concentrated on developing measurement techniques, and we are still doing that. We have not, in our own research program, really looked at control techniques because we felt that the problem was so great, the ultimate control of diesel particulate emissions that it needed a very intensive looking at in terms of the developing of the measurement techniques and the dilution tunnel and all the hardware.

So, what I will be doing is to give you a brief overview of what the open literature says about control of particulate emissions and to try to focus on looking at the engine as a system from the idea of the combustion chamber and the fuel injection system, the fuel and air that we can change going into the system and, also, the after treatment possibility, and to look at some of the technology that might fit into the long term and in the short term control.

I want you to focus a little bit on what we are really going to be talking about, and that is that we have this carbon soot that the TEM micrographs I showed you and which was talked about by Dick Wheeler, as one of the areas to controll That is one of the fractions.

We also have the soluble fraction that would come off with various solvents if we collect this on a filter or if we could collect these individual particles that are very dilute out in the atmosphere, that there is a soluble organic fraction of certain species and that we also have the sulfate fraction that comes from the sulfur in the fuel largely, that can be converted in the atmosphere or even before that in the exhaust system or in the combustion chamber or in the dilution tunnel to probably H_2SO_4, but other sulfates are also possible, since this has not really been proven precisely that it is H_2SO_4.

Where can we look in terms of present development parameters from an engineering viewpoint to get some guidance in terms of how we might control these particulates? The literature does not have a lot of particulate, NOx, hydrocarbon, CO, measurements on the LA4 cycle so that you can see the tradeoffs between fuel economy and all the emissions because you really have to look at it from this total picture of tradeoffs.

So, the best thing that I have found that you can look at is smoke measurements that are fairly crude. They probably include the hydrocarbons, in addition to the soot particles. The gaseous phase hydrocarbons, I think, are somewhat proportional to the soluble fraction, and so I think we can look at those parameters, not precisely, but we can get some indication about the variables, the engineering variables of the engine that affect these particulates.

I think we can look at the hydrocarbons and where they come from. From review or study of all the literature, the hydrocarbons come from the injector sac volumes. They come from fuel that gets on the wall. It comes from after injection. They come from the lean regions that are uncombusted in the engine.

We also have to be concerned about the lube oil, as I indicated this morning. It can come either from the rings and pistons, from the walls; it can come from the exhaust and intake valve stems. So we need to be concerned also when we talk about particulates about the sources in the engine of the lube oil.

So, with this brief introduction, I would like to go into the slides. I want to take you through basically to pick out the literature, the open literature, to pick out the several curves that illustrate some of the points, not all the points, and I am going to try to outline for you, dissecting of the engine in terms of technology. I am not going to have all the answers as to how to control it, to what levels, but I just want to go through from a systems viewpoint to set the stage because we have some people here with papers who will probably talk in more detail about these methods.

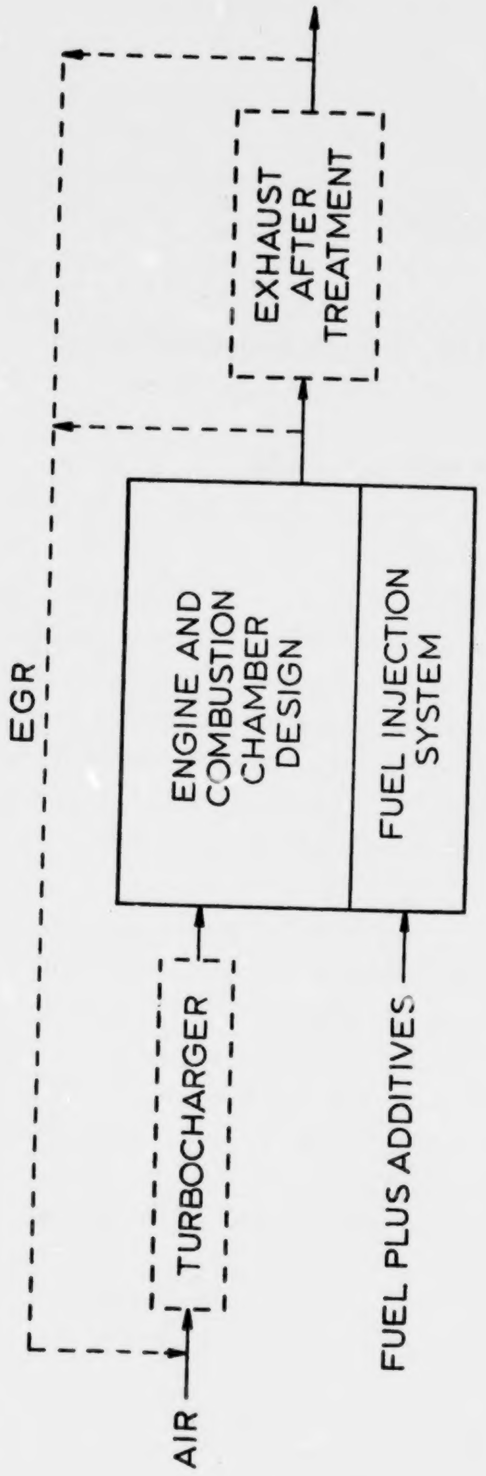
So, if I could have the first slide, please? #1

If we take a look at the engine from a systems viewpoint, we have various engine and combustion chamber design parameters, and the heart of the diesel engine is the fuel injection system.

We can look at the fuel then, plus the potential maybe of additives that might alter the emissions coming out of the exhaust pipe. The other thing that we can look at then is the exhaust after treatment devices and, as was indicated, we need to look very carefully at EGR, not from a particulate control but because it has a favorable effect on, first of all, the NOx emissions and it looks like an approach that will be needed to get the emissions from diesels down to the legislated standards. It has potentially an adverse effect on the lubricating system of the diesel engine because of the increased solids that will get into the lubricating oil.

We have, into the air, the potential of adding turbocharging, which actually is just shown in schematic. Obviously, it would be tied into the exhaust or comprex or other supercharge methods of changing the air as an input parameter to this engine.

So, I would like to have the next slide, please.? If we break the three parts of the system, then, we are going to be tal talking about fuel and fuel air modifications, engine and fuel injection design modifications and exhaust after treatment modifications. #2



AIR

TURBOCHARGER

EGR

FUEL PLUS ADDITIVES

ENGINE AND COMBUSTION CHAMBER DESIGN

FUEL INJECTION SYSTEM

EXHAUST AFTER TREATMENT

SCHEMATIC OF EMISSIONS CONTROL VARIABLES

SLIDE 1

- FUEL/FUEL AIR MODIFICATIONS
- ENGINE AND FUEL INJECTION DESIGN MODIFICATIONS
- EXHAUST AFTERTREATMENT MODIFICATIONS

Could I have the next slide, please? #3

First of all, if we break down the fuel and fuel air modifications that are possible, we can talk about fuel composition, cetane number, density, sulfur content, aromatic content. In the literature you find a lot about aromatic content in terms of the flame literature, some in the diesel. It has been a very debated thing over the years. I think there are even some problems in terms of characterizing this, even though the present ASTM procedures talk nothing about saying whether it really does influence diesel fuel aromatic content; but this is one of the variables that you find in the literature, that people are concerned that it might have an effect on smoke. Fuel additive effects, fuel fumigation, water addition, exhaust gas recirculation, largely for NOx, but it has an effect on particulates and turbocharging which is something else that is into heavy duty trucks, and people are looking at it for light duty.

First of all, let me talk about this question of additives. #4
Since lead is coming out of gasoline and it is out, it is always something that gets raised for diesels, but let me kind of set down a few of the things that I think have to happen if any additive, obviously, is going to come in to solve this problem, or practically solve it.

Regulations would be required since it would add to the cost of the fuel. Data would have to be developed to show that no adverse long or short term environmental effects of the additive or the products of the additive. Data would have to be developed to show no adverse engine effects, and all automotive diesel fuel would require additive use in order to be feasible. These are some pretty tough requirements, and I think, when you look at the additives, they really don't solve all of the problem that I tried to describe for you in the start of my talk.

Could I have the next slide? #5

This is a paper from Amoco by Ellie Shamah, which has some dat data with the barium which I think is kind of illustrative of what happens with one additive.

FUEL/FUEL AIR MODIFICATIONS

- FUEL COMPOSITION
  - CETANE NUMBER
  - DENSITY
  - SULFUR CONTENT
  - AROMATIC CONTENT
- FUEL ADDITIVE EFFECTS
- FUEL FUMIGATION
- WATER ADDITION
- EXHAUST GAS RECIRCULATION
- TURBOCHARGING

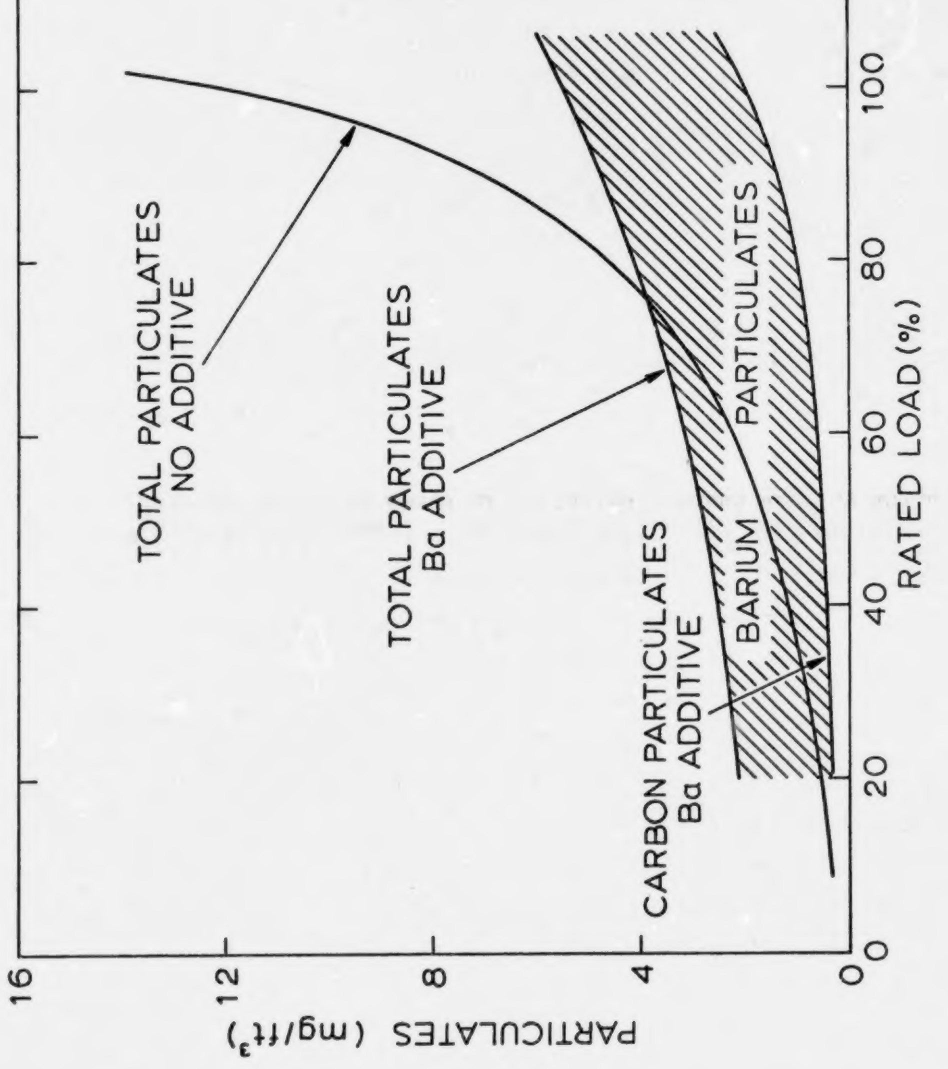
REQUIREMENTS FOR WIDE SPREAD USE OF ADDITIVES

1. REGULATIONS WOULD BE REQUIRED SINCE IT WOULD ADD TO THE COST OF THE FUEL.

2. DATA WOULD HAVE TO BE DEVELOPED TO SHOW NO ADVERSE LONG OR SHORT TERM ENVIRONMENTAL EFFECTS OF THE ADDITIVE OR THE PRODUCTS OF THE ADDITIVE.

3. DATA WOULD HAVE TO BE DEVELOPED TO SHOW NO ADVERSE ENGINE EFFECTS.

4. ALL AUTOMOTIVE DIESEL FUEL WOULD REQUIRE ADDITIVE USE IN ORDER TO BE FEASIBLE.



Source: Shamah, E. et al, SAE Paper No. 730168

SLIDE 5

This is a curve versus percent of rated load. This shows the curve, the part load curve in terms of particulate in milligrams per cubic feet of the total particulate with no additives from one engine.

The total particulates with the barium additive and the carbon particles with the barium additive here showing the barium particulates that you get out, which is not really complete control, although it does help in terms of any visibility measurement that you do, such as opacity measurement or the other smoke measurements.

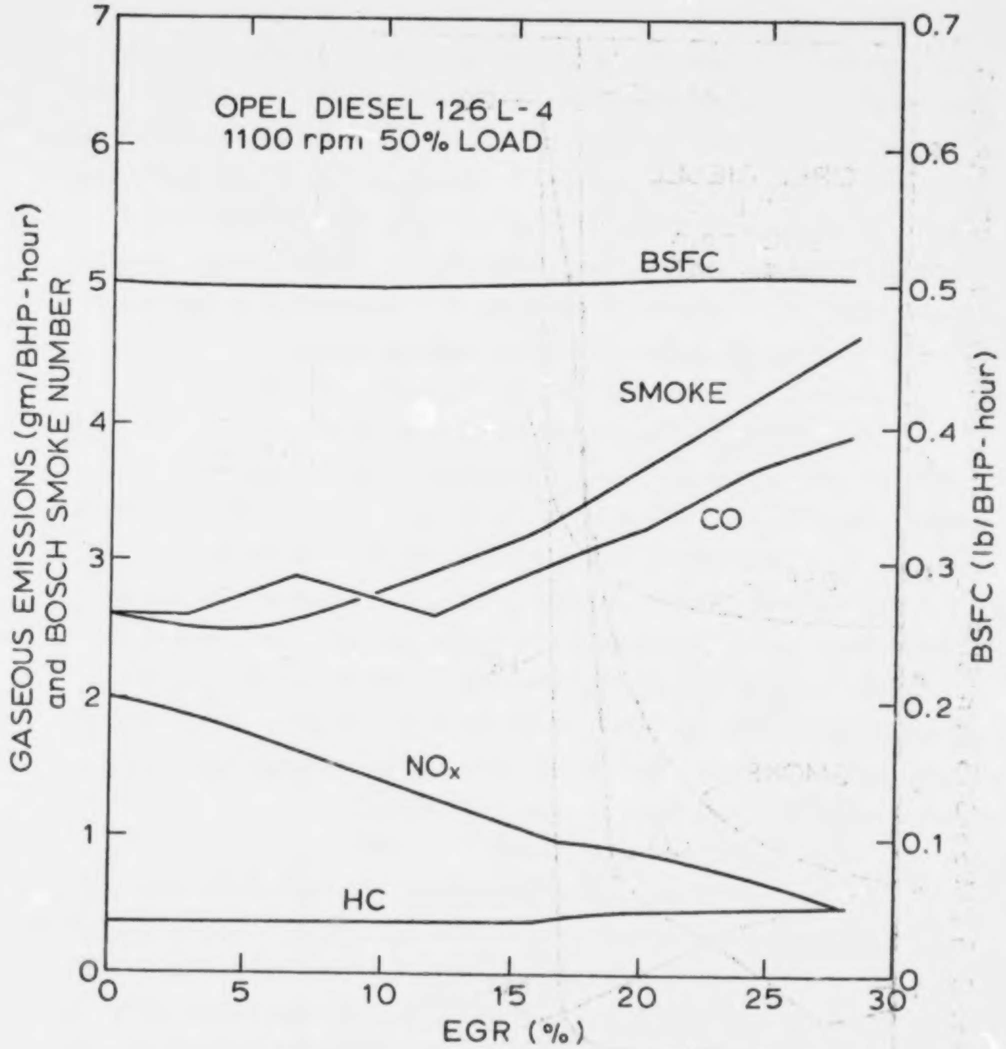
You find, in looking at the additives, that they don't give large effects; and, in fact, when you have a highly developed engine for smoke control and hydrocarbons, the additives usually have less effect than applying them to underdeveloped engines or poorly maintained engines that are smoking a lot.

Could I have the next slide, please? #6

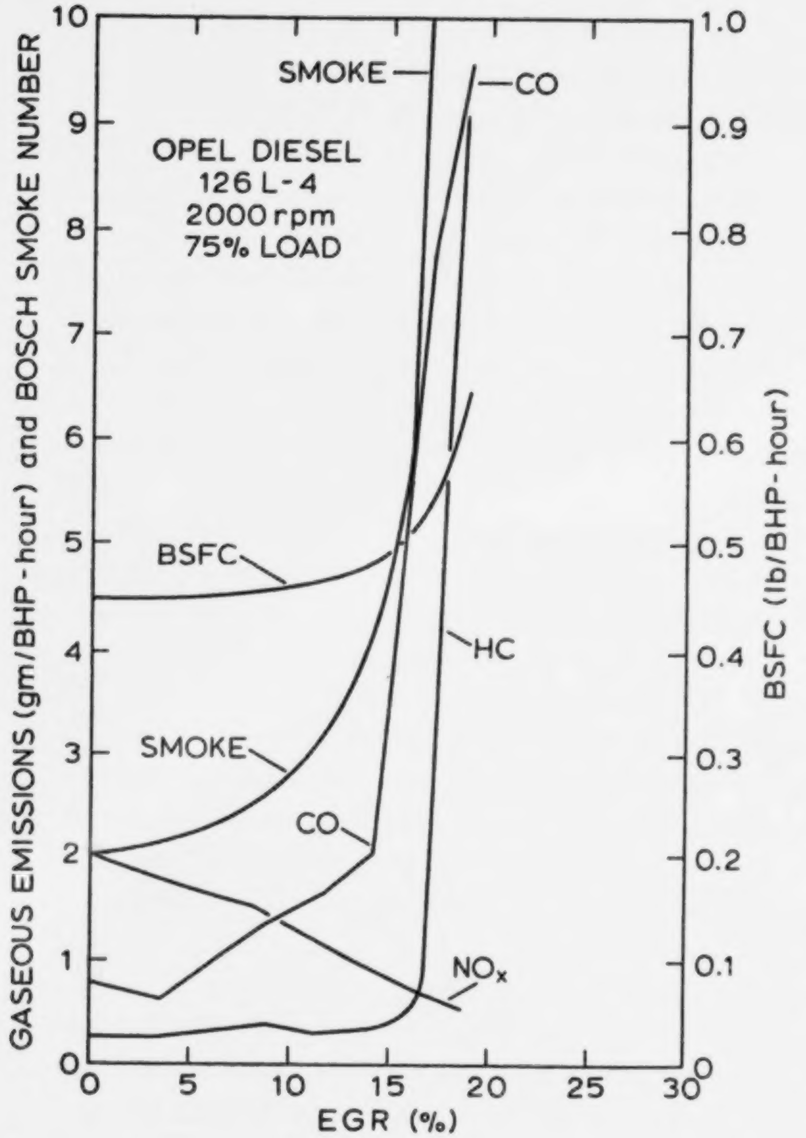
The next thing that I would like to talk about is EGR, and this is from the paper here, Automotive Emission Control, the Development Status, Trends. It is from a report, and this is the Opel diesel, the 126L at 1100 RPM and 50 percent load shown versus EGR for various gaseous emissions in terms of grams per brake horsepower hour and the smoke in Bosch number. You can see the decrease in NOx, the slight increase in hydrocarbons that Chuck talked about; and in this particular case, at some level, there was some CO increase and we see some smoke increase, and pretty flat brake specific fuel consumption curve.

Could I have the next slide? #7

As you go up in load to 75 percent load and 2000 RPM, you can see when you plot EGR that the NOx goes down nicely, but the CO and the smoke and the hydrocarbons and the BSFC is affected here as you go up in air fuel ratio getting closer to the range of 20 to 30 to 1 probably at this particular load here. You can see that it has much more effect in terms of this tradeoff.



Source: "Automobile Emission Control - The Development Status, Trends and Outlook as of December 1976"



Source: "Automobile Emission Control - The Development Status, Trends and Outlook as of December 1976"

SLIDE 7

Could I have the next slide, please?   #8

What I would like to do is now shift to engine and fuel injection modifications. We can look at the combustion systems, the combustion chamber designs, the fuel injection systems; the direct injection and the indirect engines fall out of this whole system. Direct injection engines are largely in the heavy duty, from class four in the truck on up or the medium duty and the he heavy duty because of the fuel economy and because of the fuel injection. People are largely looking at the direct injection engine, I think, in terms of right now and in the future, and it is developing advanced technology to get emissions control because there are emission standards for heavy duty vehicles, and there are in my judgment, a lot of good features when you look at the tot total emissions with direct injection engines, and I think present development is looking at turbocharging, aftercooling, sophisticated engines with sophisticated fuel injection systems to meet the standards of emissions and competitive fuel economy for the truck market.

When we get down into below class four trucks and start to penetrate into the automotive, there is a large number of swirl chamber and pre-chamber engines presently in production in the world; and it, obviously, is the kind of technology that drops out as being a logical choice in the short term.

We have to be concerned about lubricating oil consumption control. There is a possibility in the future of adiabatic engines that would run hotter and using ceramic materials which is a little bit further off in the crystal ball, but these are some of the types of things that can come in, I think, to help in the particulate control in the future.

Could I have the next slide, please?   #9

This is a curve showing the normal development tradeoffs from the CAV SAE paper on the bottom here where we plot dynamic injection timing, and we are looking at the delay period, the thermal efficiency, the noise and the nitric oxide, the black smoke and up on

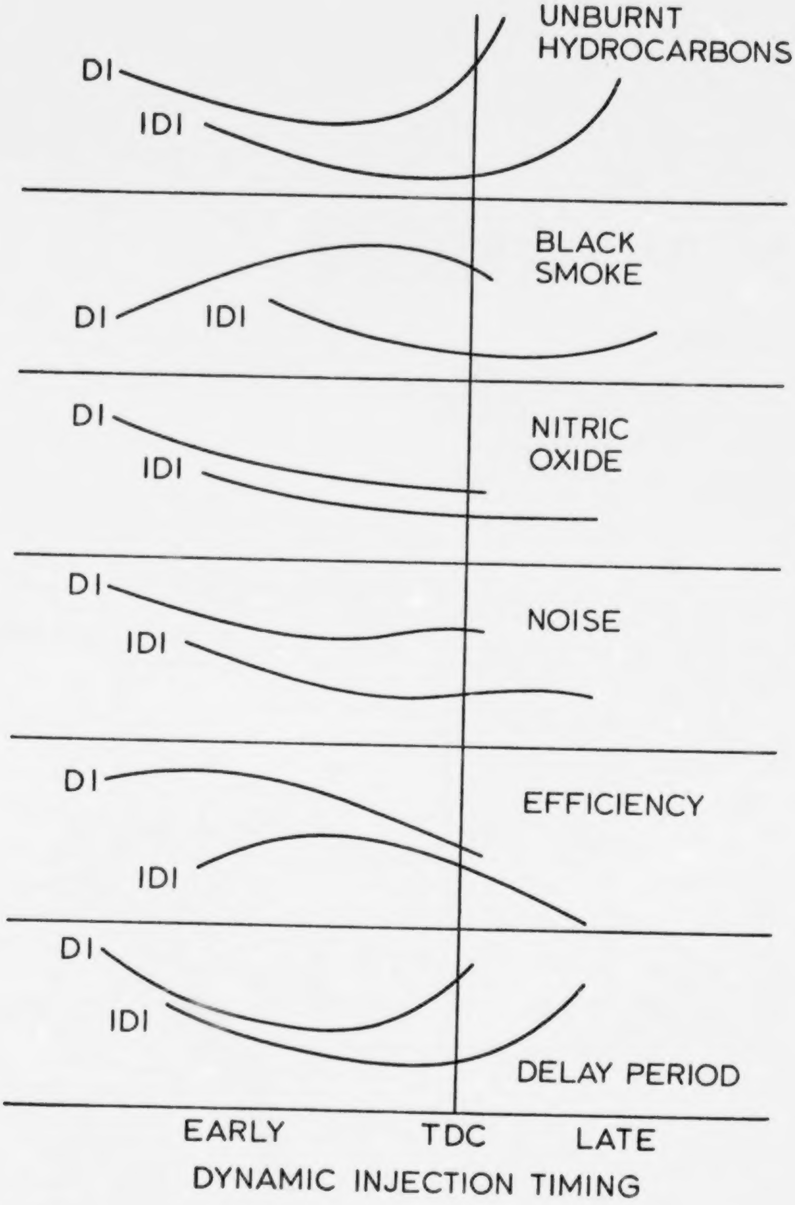
ENGINE AND FUEL INJECTION MODIFICATIONS

COMBUSTION SYSTEMS
  COMBUSTION CHAMBER DESIGNS
  FUEL INJECTION SYSTEMS
  DIRECT INJECTION ENGINES
  INDIRECT INJECTION ENGINES

LUBRICATING OIL CONSUMPTION CONTROL

ADIABATIC ENGINES

CERAMIC MATERIALS



Typical behavior of direct and indirect injection diesel engine output parameters for variation of dynamic injection timing at full speed, full load

Source: Grigg, H.C., SAE Paper No. 760126

SLIDE 9

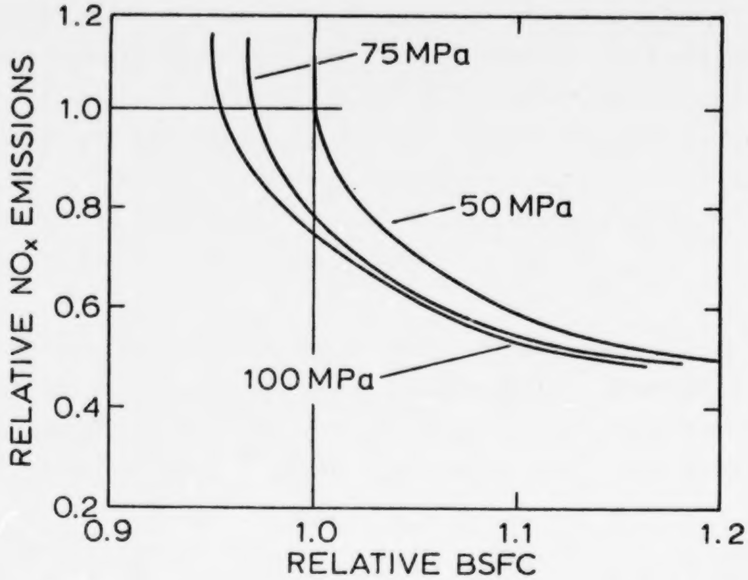
top there, unburned hydrocarbons. The thing, as I said before, that is important is that the thermal efficiency of DI's have traditionally been extremely good. IDI's can compete with a DI engine with turbocharging. The nitric oxide and the peak cylinder pressures from indirect engines are lower;;and so, it is an attractive way. The fuel system is lower in pressure. It is simpler. The combustion process takes care of a lot of the fuel air mixing, and so it makes it a good way to go in terms of the short term.

It is relatively insensitive to black smoke, and the DI can compete, obviously, at advanced timings, So, you see a number of tradeoff variables, and timing is one of the most important ones with both engines going to retarded timing to meet the NOx standards.

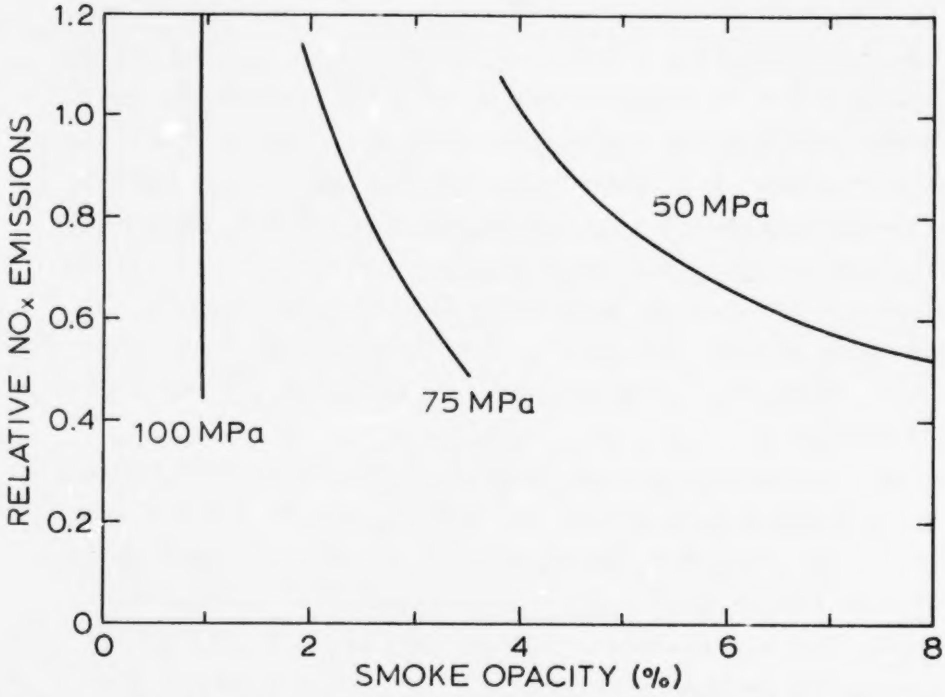
Could I have the next slide, please? #10

This is a recent paper. This is a paper by Parker. It is relating to DI engines that shows the relative NOx emissions versus the relative brake specific fuel consumption with various peak injection pressures, and it shows that the duration of injection would be changed. This is direct injection work, but it is, obviously, one of the approaches to go in DI to change the rate of fuel injection and improve further on the injection system in terms of getting fuel economy, getting NOx, and getting smoke or particulate emissions. This shows that there is some plateauing as you get to higher injection pressures out here in terms of these curves coming together, but it does show that you can, with this particular advance fuel system. This is a research fuel system, I want to point out, but you can get reduced NOx at the same fuel consumption.

Down here we have the relative NOx emissions plotted versus the smoke opacity and you can see that you can get a points here where there is relative insensitivity. You are still at 1 percent, and 1 percent is still a lot of particulate in emissions, and we are starting to talk about grams per mile in that. It does not make it that it is zero, but it does show that you can get NOx



Effect of injection pressure on the NO_x-BSFC relationship as injection timing is retarded



Effect of injection pressure on the NO_x (102 mm stack diameter) smoke relationship as injection timing is retarded

Source: Parker, R.S., SAE Paper No. 760125

SLIDE 10

control, and you also can get smoke control with present measurement techniques in this particular engine by going to sophisticated fuel systems, and It is one of the approaches that needs a lot of research.

Could I have the next slide, please? #11

There is very little data in the literature comparing DI engines to pre-chamber engines, and this is some literature from Canada. It is from the mining industry from Bruce Stewart, the Federal Government of Canada. He has run some raw exhaust particulate measurements in terms of collecting on a filter the concentration versus the fuel air ratio on both an IDI engine and a DI engine. They are at different speeds. They are different engines, and they happen to show these kinds of characteristics. I would not want to extrapolate this, but I only show it as some of the representative data that is in the literature. There is a need for a lot more work, and I understand that Southwest Research is going to do more of this because there is a need to do this to find out the part load characteristics; and this particular slide shows the DI more favorable than this particular IDI engine versus fuel air ratio or versus load.

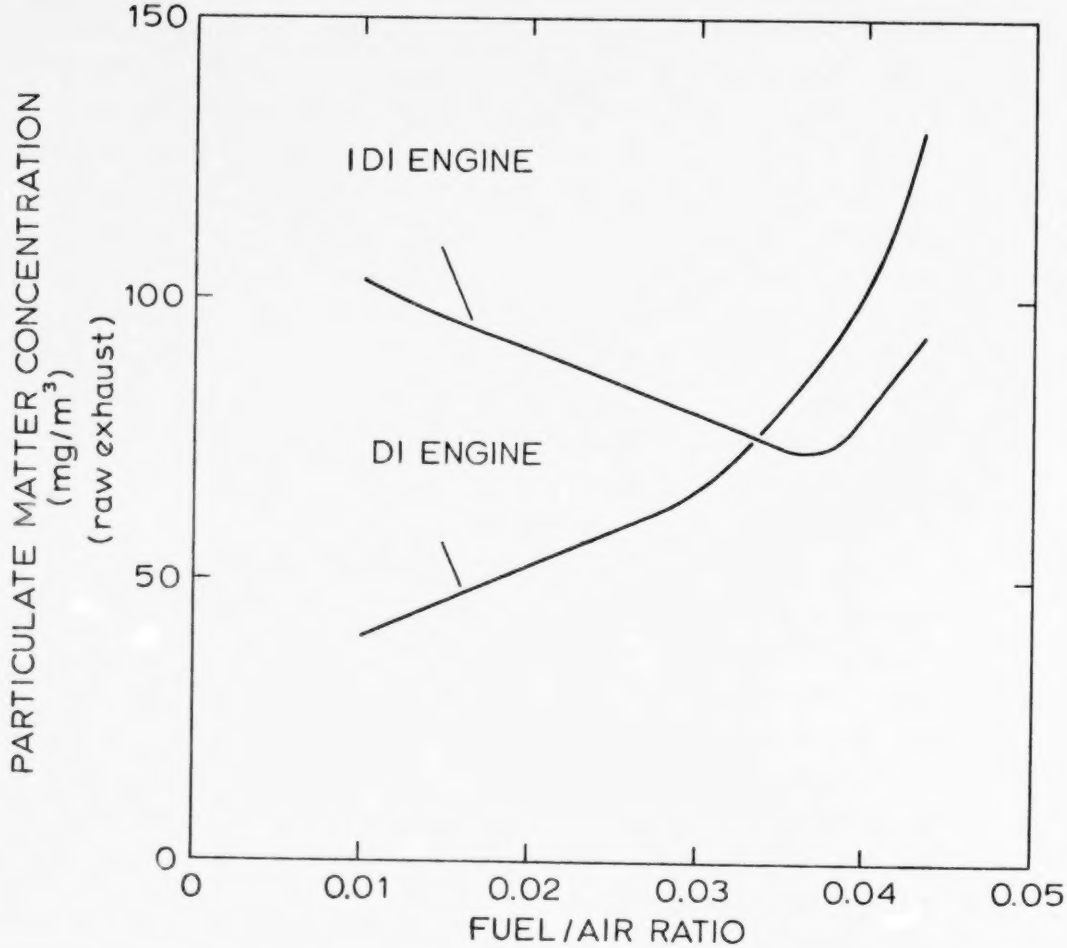
Could I have the next slide? #12

The other thing that I talked about is this SAE paper, and this is an example of the valve stem oil seal in terms of changing the gaseous phase hydrocarbons in grams per mile with a series of repeats in terms of the changed design, in terms of showing how that brings the hydrocarbons down.

Obviously, there is nothing, in terms of the particulate emissions or the soluble fraction, which I talked about before; but this is the type of development that has to go on to fine tune these particulate emissions.

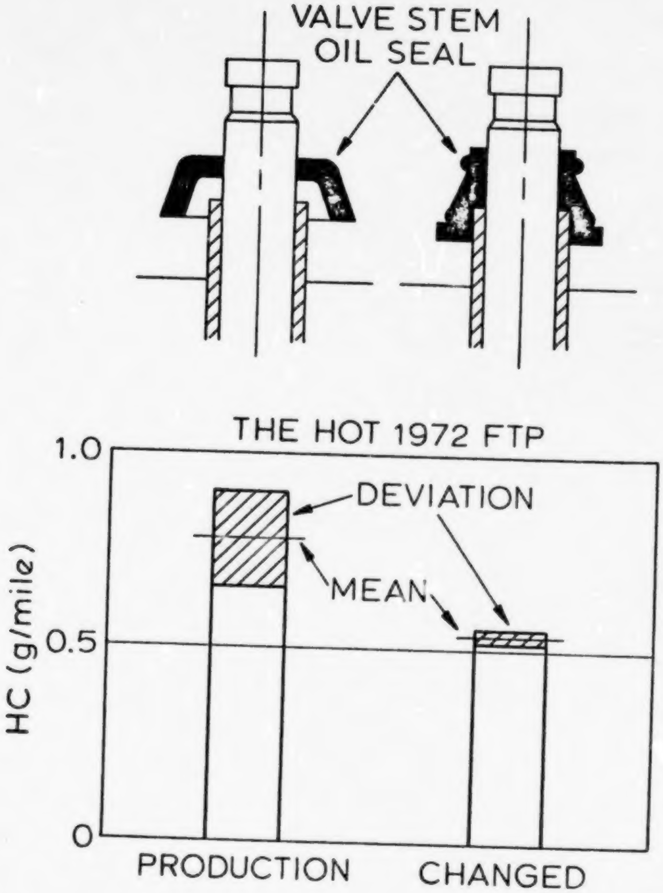
Could I have the next slide? #13

The other approach is after treatment with catalyst, water scrubbers, or dry scrubbers, some kinds of traps which Karl Springer is going to talk about, and reactors. I have



Source: Stewart et al, "Some Characteristics of Particulate Emissions in Diesel Exhaust". Mining Equipment

SLIDE 11



Effect of intake and exhaust valve stem oil seal change on HC

Source: Amano et al, SAE Paper No. 760211, 1976

AFTERTREATMENT MODIFICATIONS

- CATALYSTS
- SCRUBBERS
- TRAPS
- REACTORS

Could I have the next slide? #14

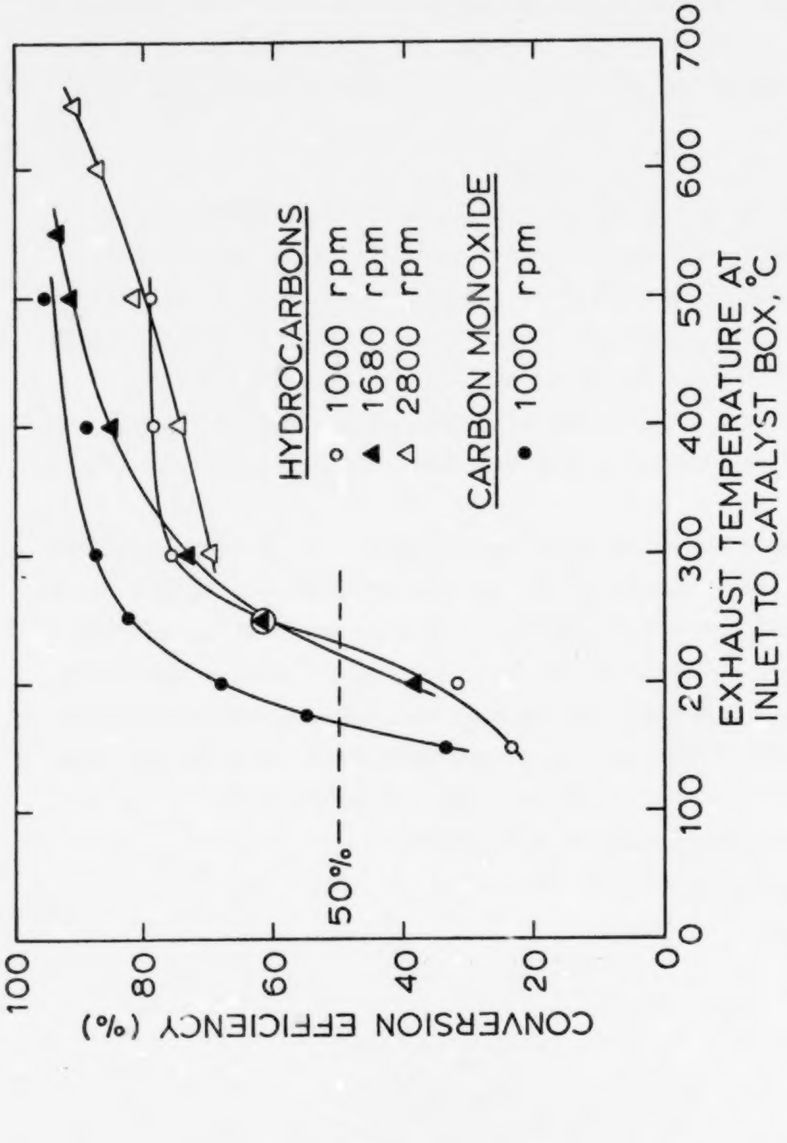
This is showing the exhaust temperature with a catalyst box with diesel exhaust in terms of the hydrocarbons, with carbon monoxide in terms of the conversion efficiency, in terms of a platinum catalyst, in terms of showing the effect so that catalysts do work. I think there is a need for a lot more development work to getting them close to the engine. The diesel has a variable air fuel ratio. It has this soot problem that coats the catalyst, and it needs to be developed to match the diesel and to match the cycle and to match the application, and a lot of work needs to be done in this area.

Could I have the next slide? #15

This is something that hopefully maybe Dick Wheeler will talk about that you find in the literature in this earlier SAE paper, the Ricardo suggestion of the spiral filter and the idea of putting a catalyst. In fact, that is one of the things that looks attractive is to combine and somehow store these particulate emissions and burn it off during heavy load conditions because that is one of the problems with any kind of a trapping device is that you collect.

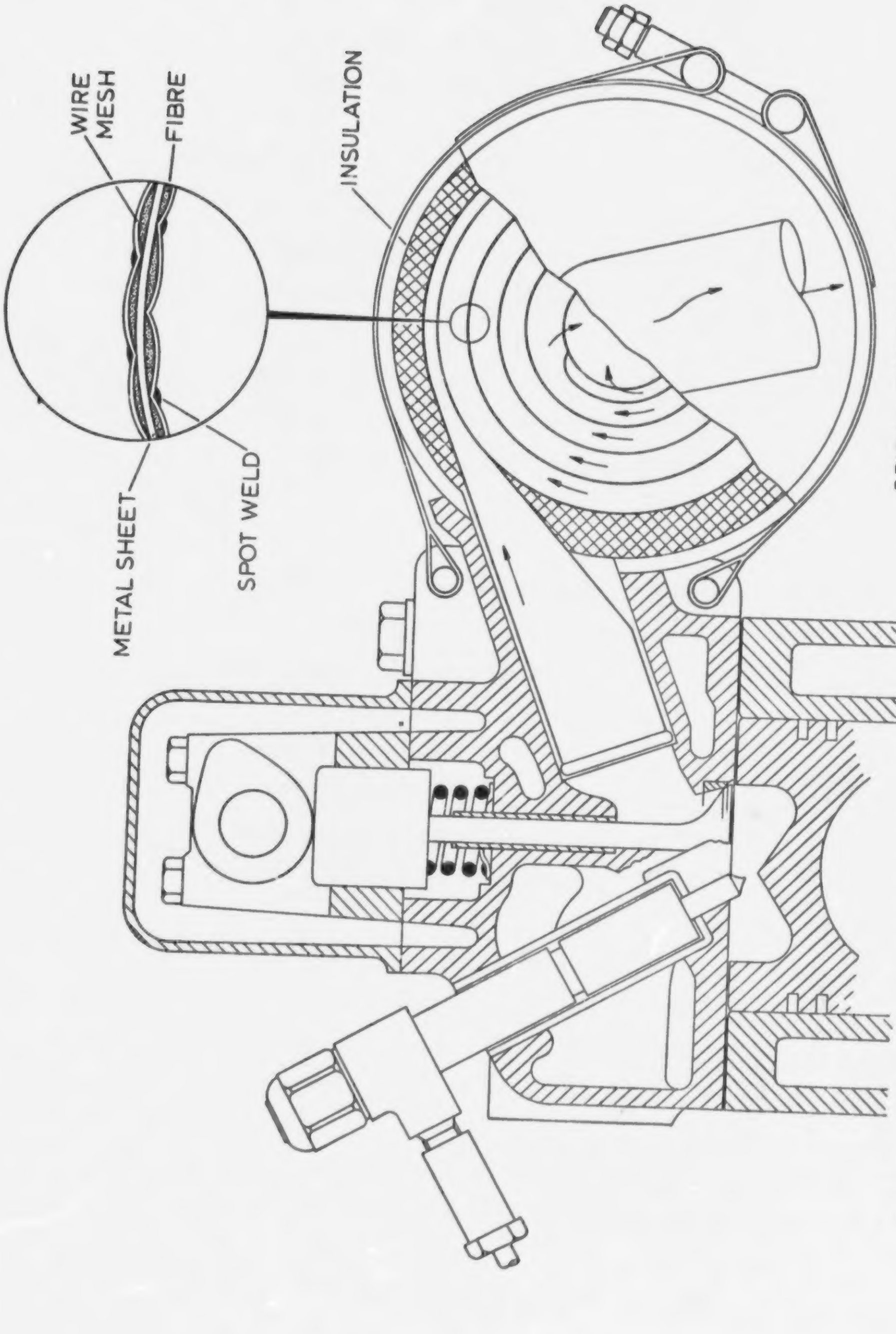
There is a lot of mass of particulate. It is very light and low density. So, there are some serious processing problems in the consumer's hands of how do you keep the pressure buildup and how do you get the control on a cycle; but, obviously, some of these concepts are added together. If we know what we are really reducing, maybe there will ultimately be a long term research solution; and, hopefully, we will be able to cut down the particulate emissions once we really define what we are chasing.

With that I would like to end.



Source: *Sercombe*, Platinum Metals Review, Vol. 19, No. 1, Jan. 1975

SLIDE 14



SPIRAL SOOT SCRUBBER

Source: Collins, D. et al, SAE Paper No. 750904, 1975

SLIDE 15

MR. HURN: Thank you, John. That was an excellent overview of some of the options that we have and some of the possibilities and directions we are going.

Now, before we move just directly into the control technology part of the afternoon presentations, let us pick up a bit more on characterization. There will be a couple of papers there.

The first of those is by Mr. Lies, representing Volkswagen, to tell us how they see diesel exhaust.

MR. LIES: Gentlemen, I present today test data from a comparison of diesel and gasoline fueled vehicles. In this study, besides the regulated emissions, we have measured the particulate and the sulfate emissions.

The emission levels of the regulated components, on an average, are well below the applicable standards and are not presented here. The measurements were done using the dilution tunnel technique throughout.

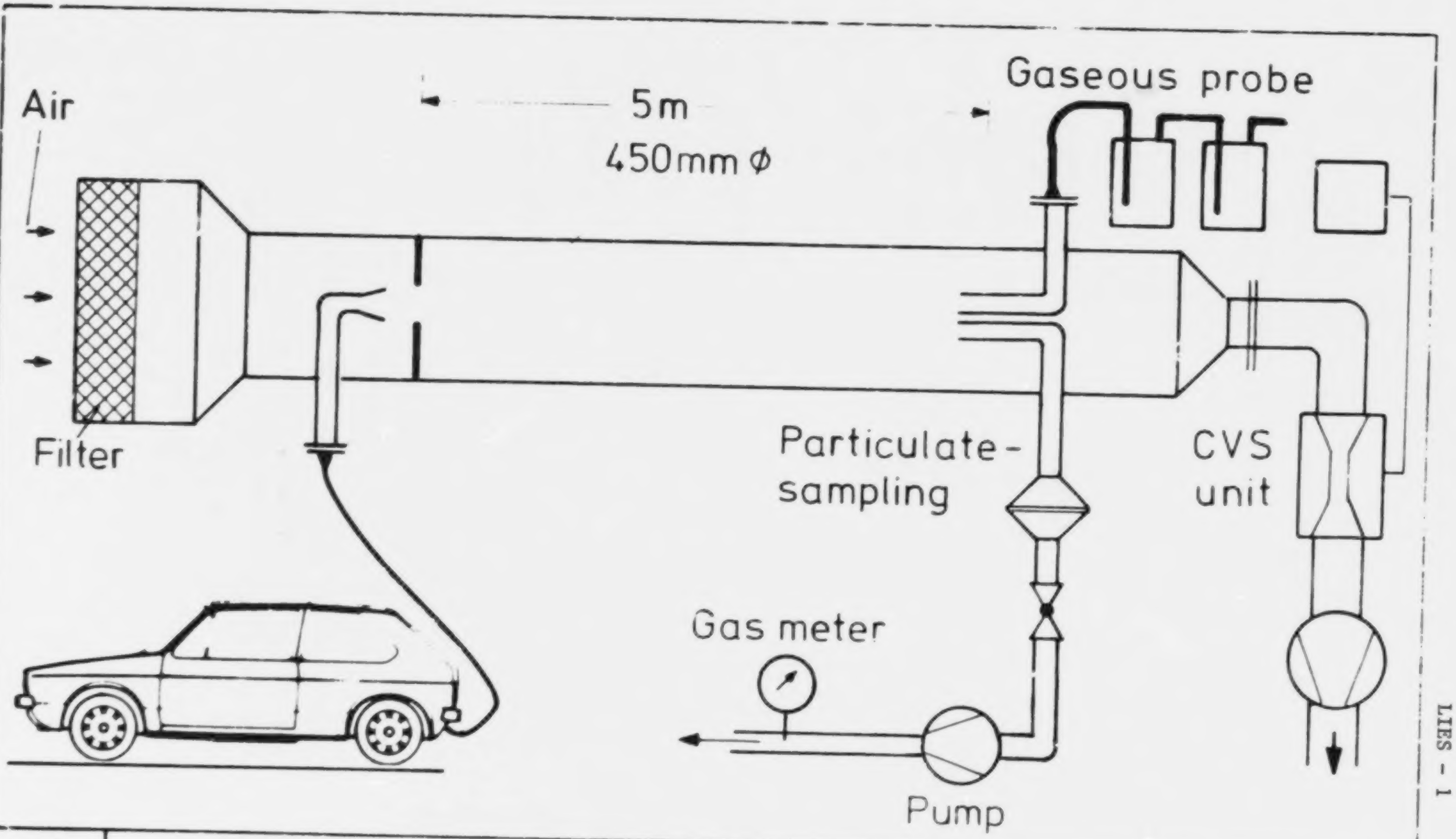
The first slide, please? #1

Our dilution tunnel is designed in accordance with the EPA recommended practice. The overall length is about six meters. Its interior diameter is about 0.45 meters. The probe for the isokinetic sample drawing is located at the end of the tunnel.

The particulate samples were collected on a fluorpore filter, pore size one micron, diameter 70 millimeters. The filters were conditioned in accordance with the EPA procedure. The microbalance for weighing the filters before and after sampling is located in a temperature and humidity controlled chamber.

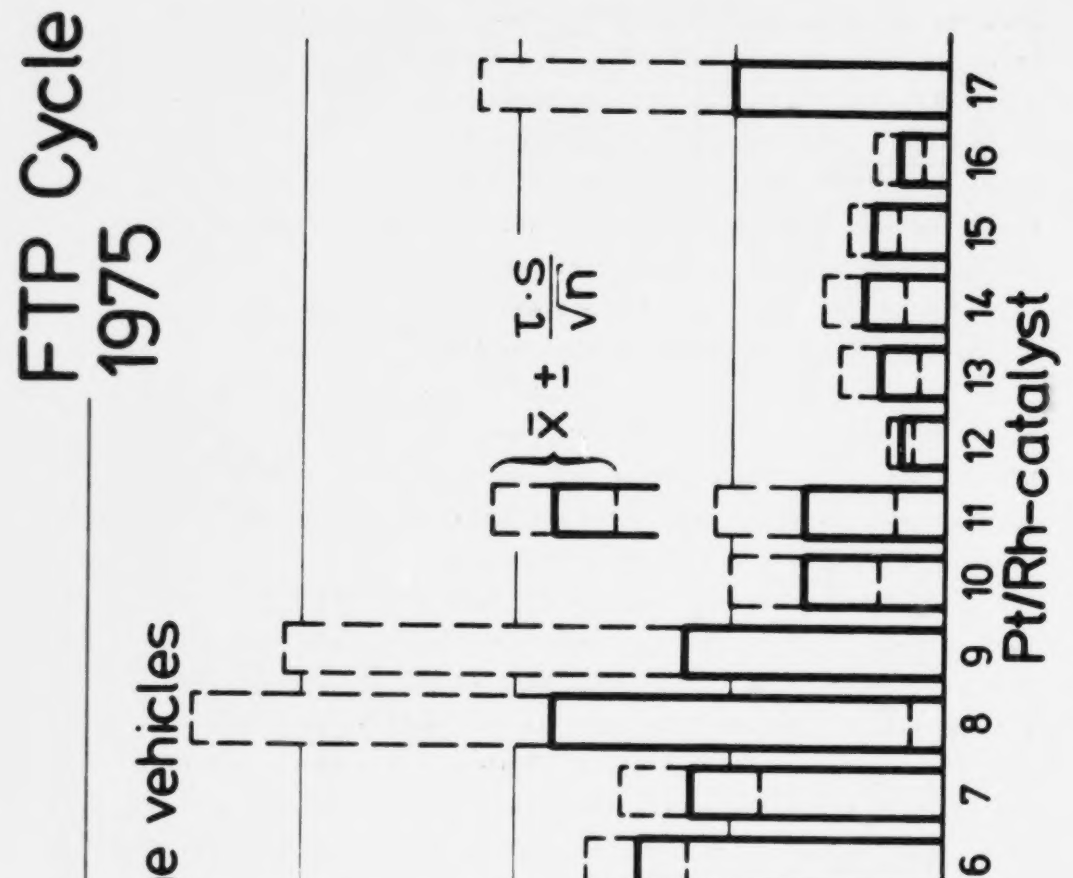
The sulfate analysis is performed using the EPA barium chloranylate method. The vehicle tested in our investigation was run over three operating modes. These included the driving cycle of the federal test procedure, of the sulfate emission test, and of the highway fuel economy test.

The next slide shows the results of the particulate measurements on gasoline vehicles, five non-catalyst and 12 catalyst equipped #2



Diesel sampling system

FE
75 63 27


FTP Cycle
1975
Particulates
100
mg/mi
75
50
25
0
Vehicle No.
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
Gasoline vehicles
Non-catalyst
Pt/Rh-catalyst
$\bar{x} \pm \frac{\tau \cdot s}{\sqrt{n}}$

cars. In this slide are only shown the results obtained during the FTP cycle. It could be stated that the particulate output from the gasoline vehicles does not depend significantly on the driving cycle. The data given in this slide indicates that the particulate emissions due to the vehicle type ranged on the following levels: 7 through 40 milligrams per mile for non-catalyst cars; 5 through 45 milligrams per mile for catalyst equipped vehicles. Thus, there are no significant differences between catalyst and non-catalyst equipped vehicles.

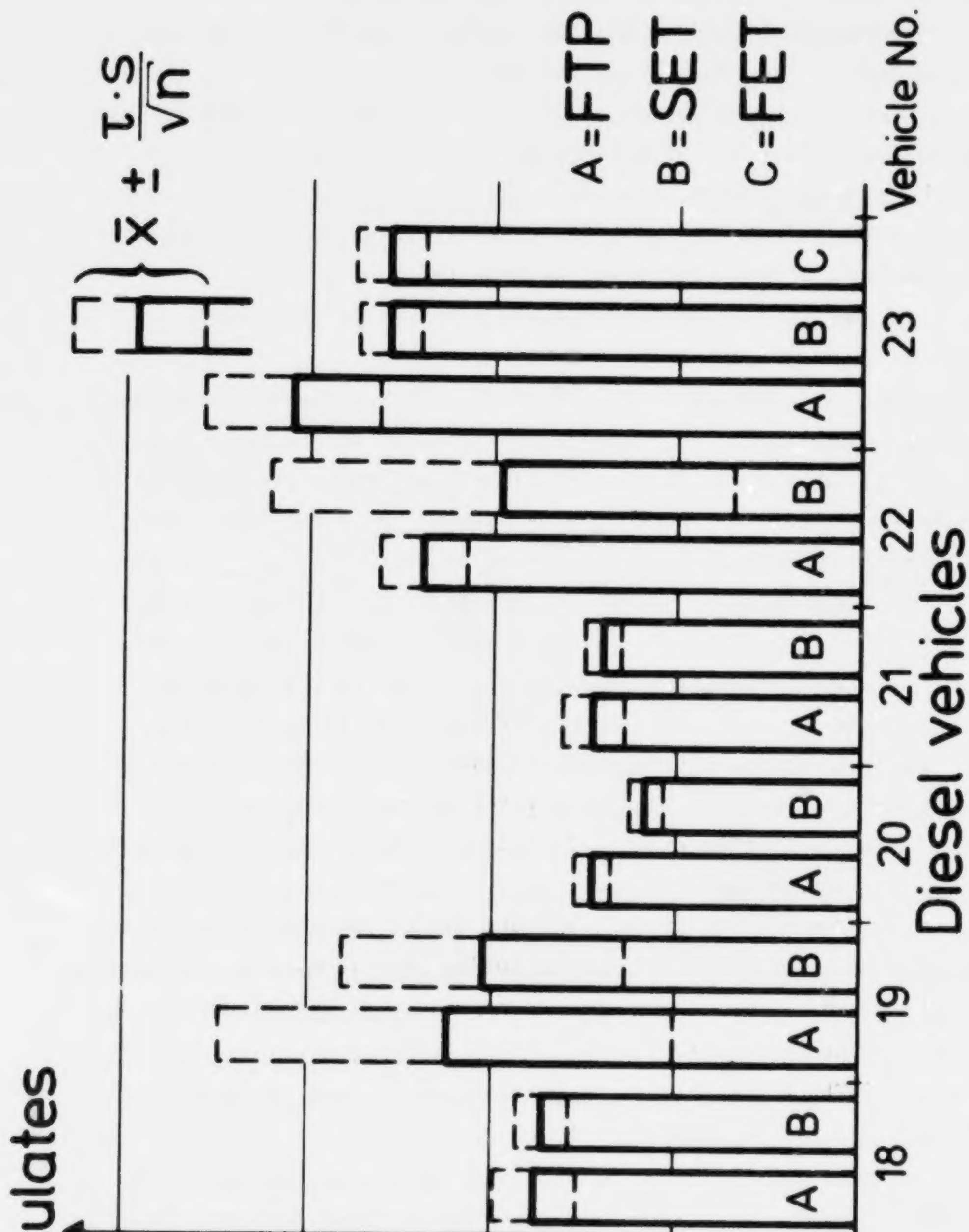
The reason for these findings may be the limited number of the cars and the high spread of the results.

The next slide shows the results of the particulate measurement on diesel cars. The tests were performed according to the FTP and SET cycle. In addition, on one case, the highway fuel economy test was run. From these few data, it can be seen that there is no dependence from the driving cycle. #3

The data obtained during the FTP indicate that the values vary between 245 milligrams per mile and 620 milligrams per mile. Thus, on average level, the diesel cars tested in this program emit 20 times as much particulates as the gasoline cars. Note, too, the details of these results. Number 18 represents a Rabbit diesel. Its particulate emission level is 350 milligrams per mile. When using EGR on the same vehicle, the particulate emissions increase up to 450 milligrams per mile, pointed out by number 19.

Number 20 and 21 are results from Rabbit diesels using turbocharging. The mean of the particulate results is only 265 milligrams per mile. The tendency of this data is in agreement with levels of exhaust particulates reported by other manufacturers; but, to fully quantify the effects of the control techniques used, further investigations are necessary.

Vehicle number 22 and 23 are Audi 100's equipped with five cylinder diesel engine. The particulates of these cars are about 500 milligrams per mile on average level.


Particulates
mg/mi
800
600
400
200
0
$\bar{x} \pm \frac{s \cdot t}{\sqrt{n}}$
A=FTP
B=SET
C=FET
A
B
A
B
A
B
A
B
A
B
A
B
C
18
19
20
21
22
23
Vehicle No.
Diesel vehicles

Next slide? #4

The next slide shows the results of our sulfate measurements. In this program, we have tested two non-catalyst cars, eight catalyst equipped cars, and two diesel cars. This slide shows the emission results obtained during the FTP cycle. The data indicate that the sulfate emissions from gasoline vehicles are very low. In general, they are less than one milligram per mile. It can be stated that on average level non-catalyst and catalyst equipped vehicles emit sulfates in the same order of magnitude.

Diesel engines, of course, generate greater rates of sulfates due to the higher sulfate content of the fuel. The sulfur content of the gasoline fuel we used in our investigation was .026 percent by weight.

Our diesels run on the available number two fuel with the sulfur level of .23 percent by weight. Thus, a difference in the sulfur content is about one order of magnitude.

Accordingly, about the same ratio was found in the sulfate emissions of the gasoline and diesel fuel engines.

The next slide? #5

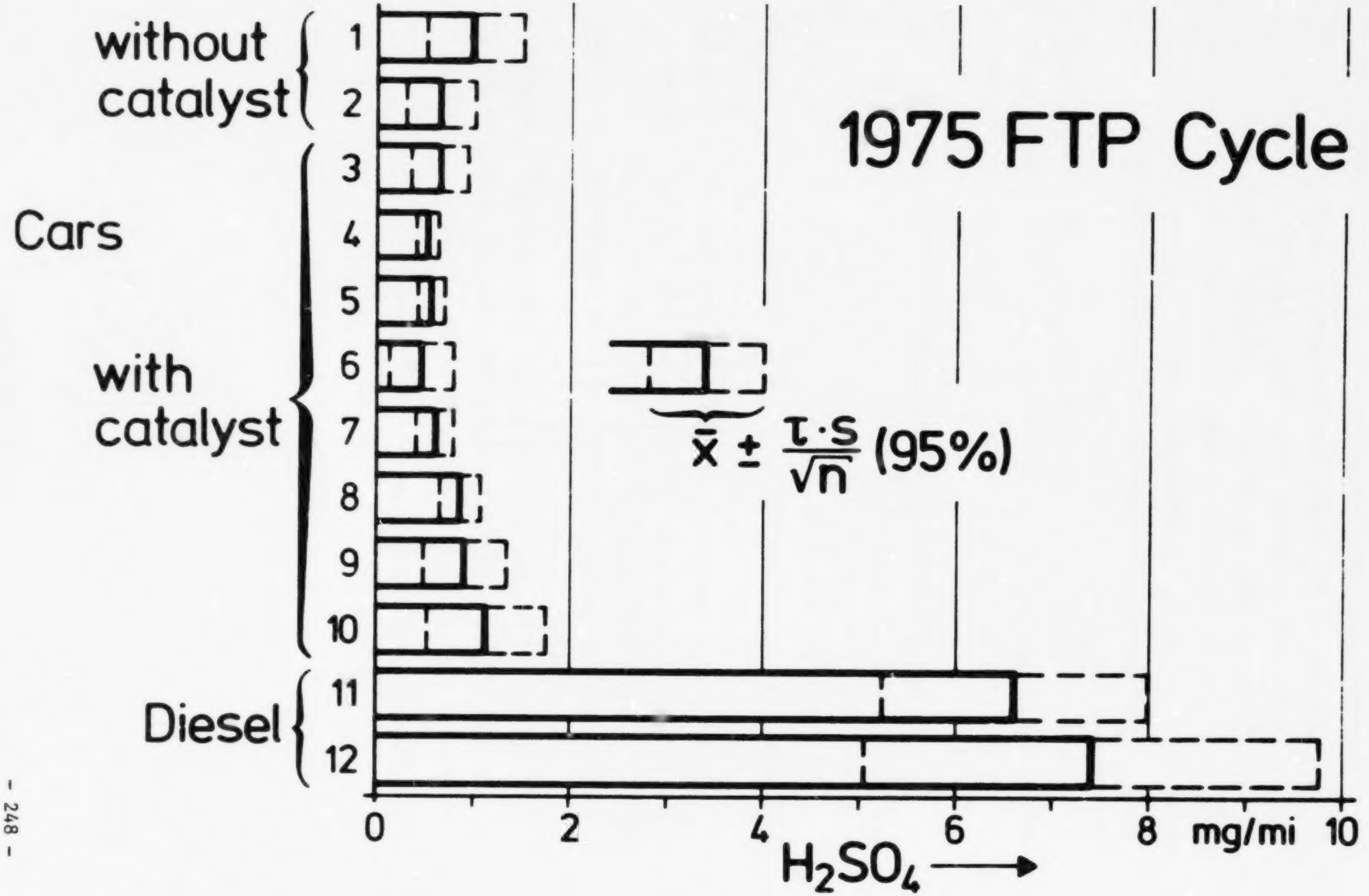
This slide shows the conversion rate from fuel sulfur to sulfate in detail. During the FTP cycle, we found conversion rates from 0.4 through 0.8 percent for gasoline fueled vehicles. The diesels converted about 1.3 percent of their fuel sulfur to sulfate.

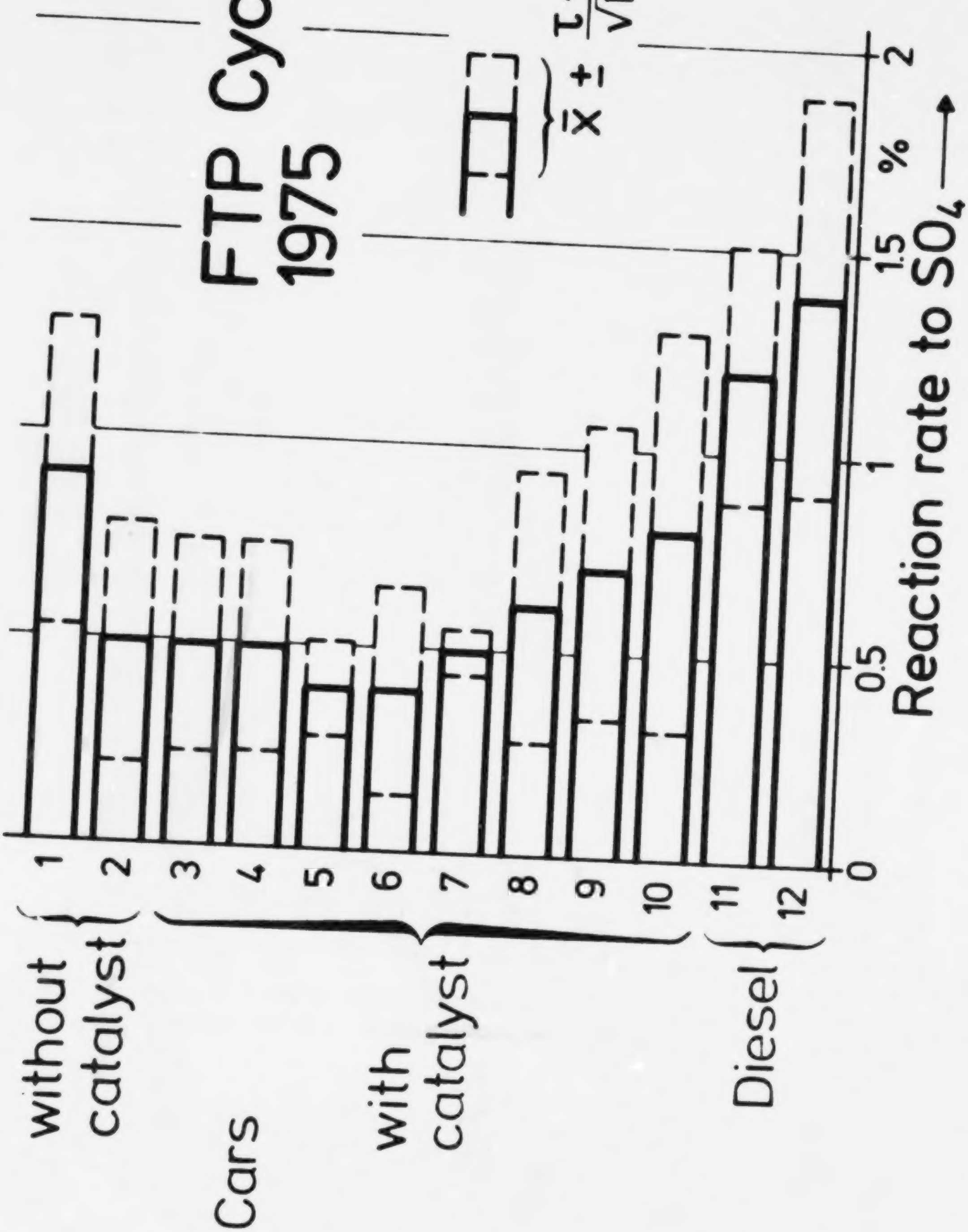
Next slide? #6

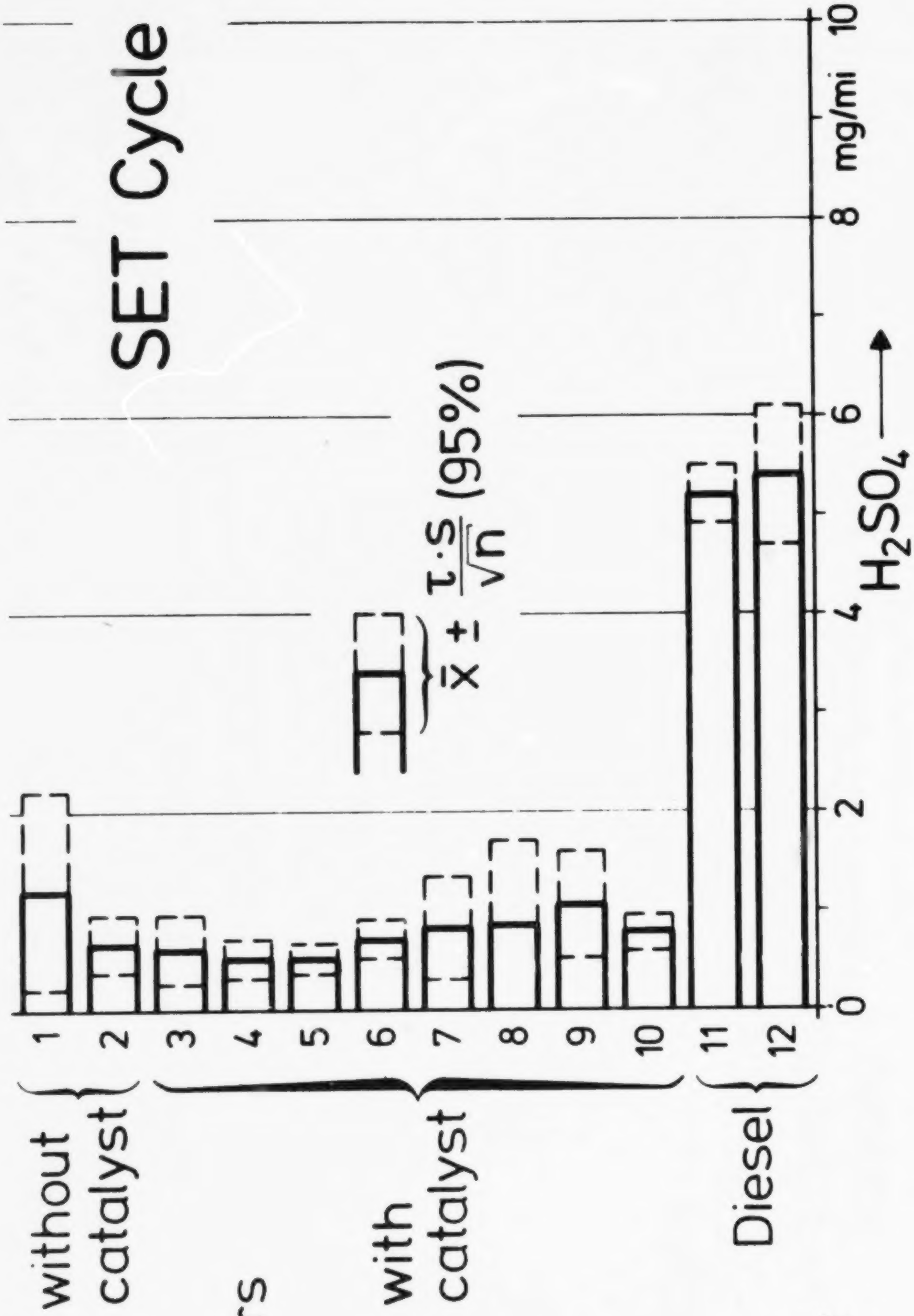
For the SET cycle, we found higher conversion rates; but due to the lower fuel consumption during this test, the resulting sulfates are in the same order of magnitude as the sulfates resulting from the FTP cycle.

Thank you.

1975 FTP Cycle




FTP Cycle
1975
$\bar{x} \pm \frac{t \cdot s}{\sqrt{n}}$
Cars
without catalyst
with catalyst
Diesel
1
2
3
4
5
6
7
8
9
10
11
12
0
0.5
1
1.5
2
%
Reaction rate to SO_4


SET Cycle
$\bar{x} \pm \frac{\tau \cdot s}{\sqrt{n}}$ (95%)
Cars
without catalyst
with catalyst
Diesel
1
2
3
4
5
6
7
8
9
10
11
12
0
2
4
6
8
10
mg/mi
H_2SO_4 →

MR. HURN: Thank you, Mr. Lies.

The next paper, again, addressing generally, characteristics of the exhaust and how they are measured by Mr. Cornetti of Fiat.

Mr. Cornetti?

MR. CORNETTI: First of all, I beg your pardon for my bad English.

Under Contract DOT-TSC-1424, we are studying the behavior of #1
a new European diesel engine family from the point of view of fuel
economy, regulated and unregulated emissions.

Next slide, please. #2

The main characteristics of this new diesel engine family are presented in this slide. Gross SAE power output ranging from 7230 horsepower can be obtained.

Next slide, please. #3

The first evaluation of regulated emission is presented in the slides versus inertia weights for different axle ratios. Composite fuel economy is also reported. From these data, it is possible to say that diesel engines can represent a very interesting approach for achieving better fuel economy. In fact, composite fuel economy higher than 35 miles per gallon for 3,000 pound car can be achieved. Furthermore, by optimizing the fuel injection system and/or by turbocharging the diesel engines, goals of .41, 3.4, 1.5 gram per mile of HC/CO/NOx can probably be achieved without affecting fuel economy. Unfortunately, the presence of a high quantity of p particulate matter in the gas exhaust by diesel engines and, especially, the possibility that organic compounds absorb only particulates that can be carcinogenic represent a serious limitation to the penetration of diesel-powered cars into the domestic auto fleet.

Next slide, please. #4

To characterize particulates that absorb chemical compounds, we have designed and built a dilution tunnel according to EPA suggestions.

TITLE: DATA BASE FOR LIGHT-WEIGHT AUTOMOTIVE DIESEL POWER PLANT

OBJECTIVE: TO OBTAIN A DATA BASE ON THE PERFORMANCE, FUEL ECONOMY, REGULATED AND UNREGULATED EMISSIONS OF A LIGHT-WEIGHT PRE-CHAMBER DIESEL ENGINE FAMILY

CONTRACT No.: DOT - TSC 1424

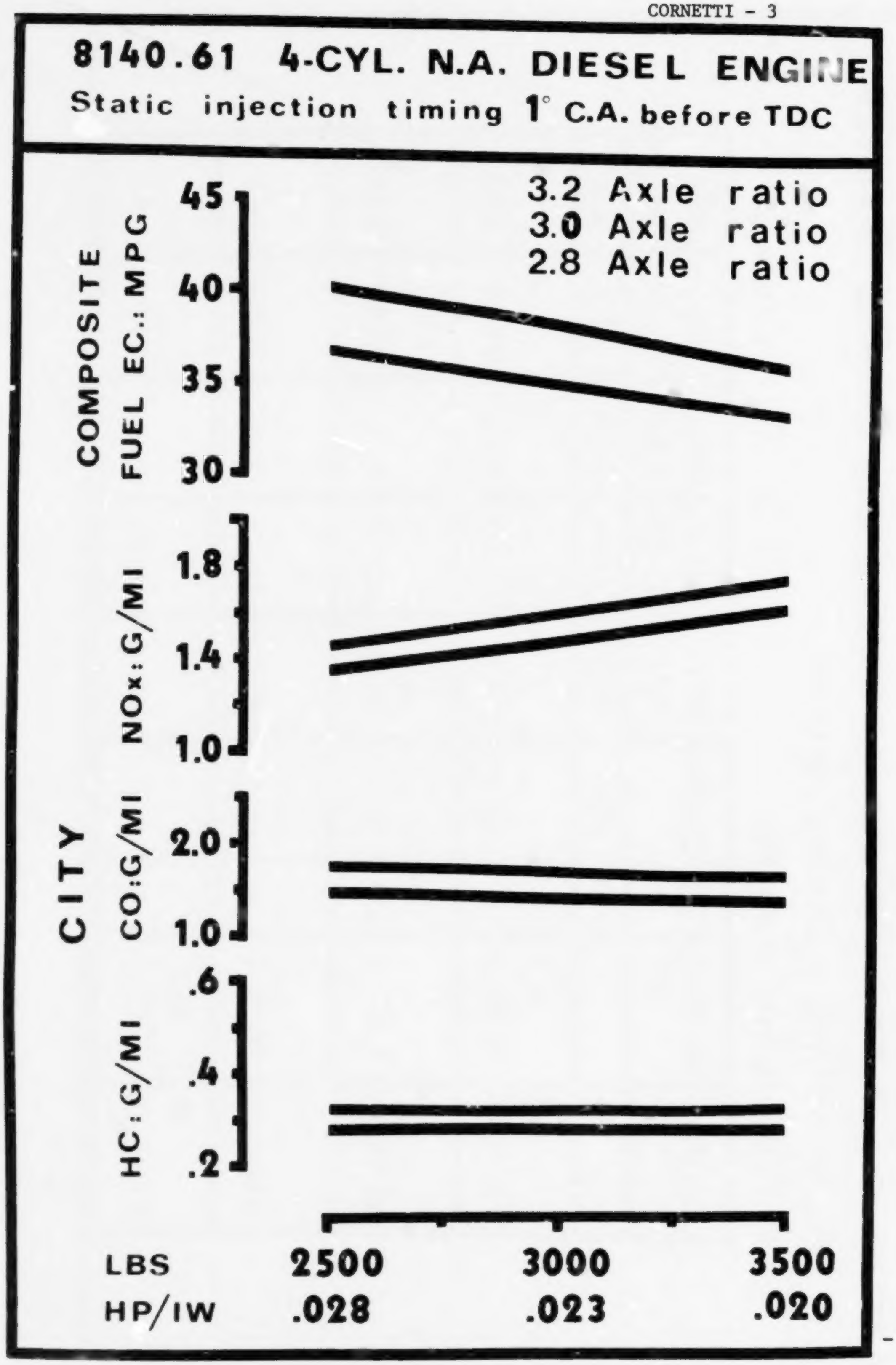
CONTRACTOR: FIAT RESEARCH CENTER
10043 ORBASSANO - ITALY

MAIN CHARACTERISTICS OF THE 8100 ENGINE FAMILY

Bore : 93mm – Stroke : 90mm

✱ Prototype engine

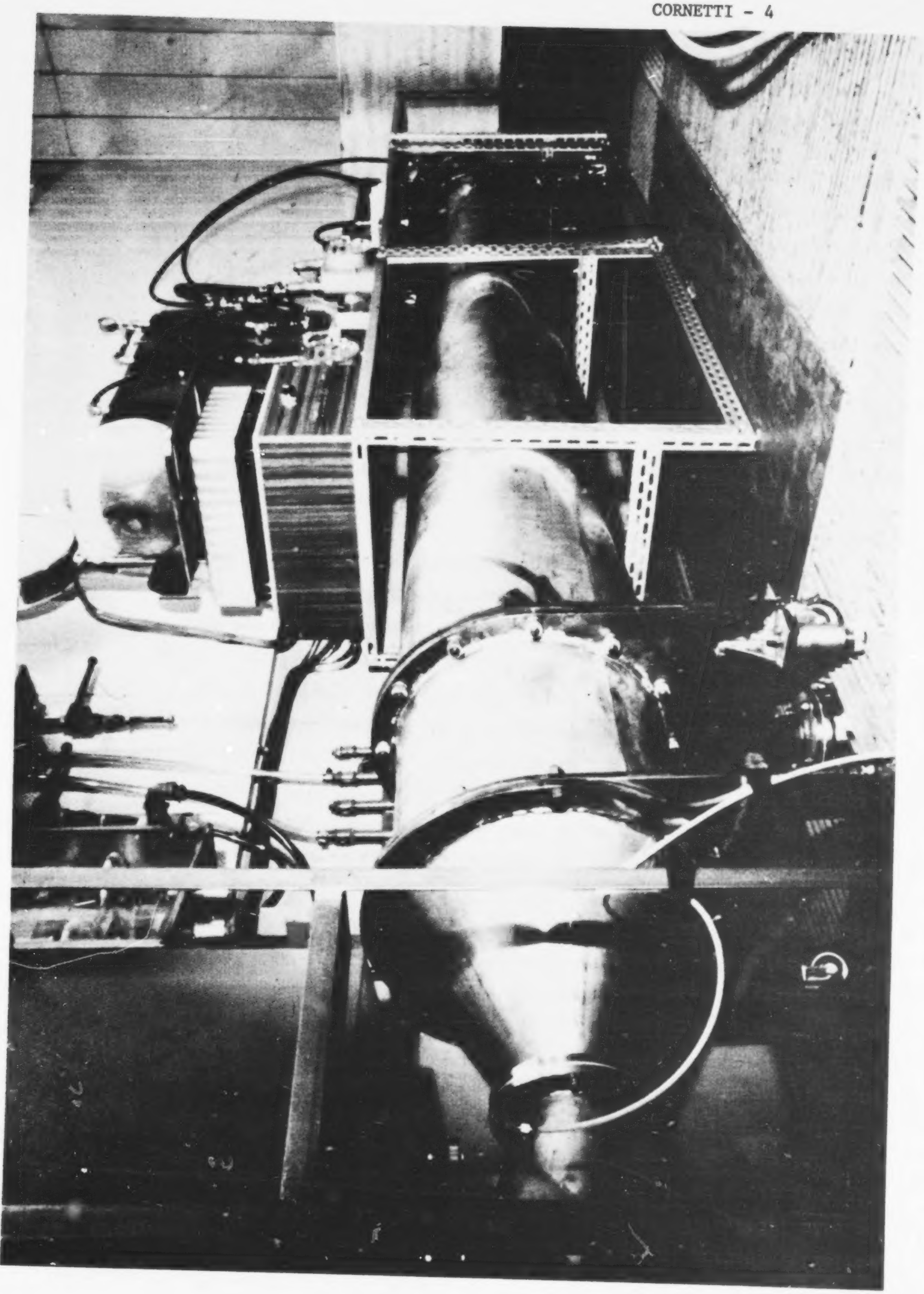
Engine	Version	Cyl.	Displac	Max SAE BHP Gross		Max SAE Torque Gross		Net Weight
		nº	dm^3	KW	rpm	Nm	rpm	Kg
8144.61	N.A.	4	2.4	51.4	4200	144	2400	220
✱ 8144.81	T.C.	4	2.4	66.2	4200	181	2000	230
8164.61	N.A.	6	3.7	73.5	4200	216	2400	275
✱ 8164.81	T.C.	6	3.7	95.5	4200	265	2400	290



8140.61 4-CYL. N.A. DIESEL ENGINE

Static injection timing 1° C.A. before TDC

CORNETTI - 4



Next slide, please. #5

To analyze particulate absorbed compounds, we use a procedure suggested by EPA, integrated by a procedure we used in the past to characterize the burner soot. Then I try to explain this new procedure. The research work results from cooperation between the Fiat Research Center and the combustion laboratory of the Italian Research Council. Because of lacking a dilution tunnel until now, we have worked on the burner soot, but starting from next month, we will begin to study organic compounds absorbing diesel exhaust particulates.

Thus, now I will describe our approach by taking into account only soot samples coming from the burner. The analysis of PCAH, polycyclic aromatic hydrocarbons, in soot samples usually involves extraction of such compounds from solid particles, followed by separation and identification carried out with a combined gas chromatic mass spectometric system.

In a previous paper we have shown that the main limitation of this procedure was due both to the extraction techniques that are incomplete and to gas chromatography that was unable to elude high molecular mass compounds. In addition, we have verified that direct sampling of the solid material into the injection block of a gas chromatograph heated at high temperature is a method much more rapid and efficacious than solvent extraction and that the direct sampling of solid particles into mass spectrometry by solid probe heated up to 500 degrees Centigrade under high vacuum was well suited to evidence of polycyclic aromatic hydrocarbons with molecular weights beyond coronene.

The purpose of this presentation is to suggest the analysis of polycyclic aromatic hydrocarbons absorbed on a particulate by thermogravimetry and mass spectrometry.

Next slide, please. #6

This slide shows the thermogravimetric curve of soot. The most important weight loss takes place up to 500 degrees Centigrade. From 600 degrees Centigrade, gas analysis in line to thermogravimetric apparatus shows the presence of hydrogen, ascribed to soot pyrolysis.

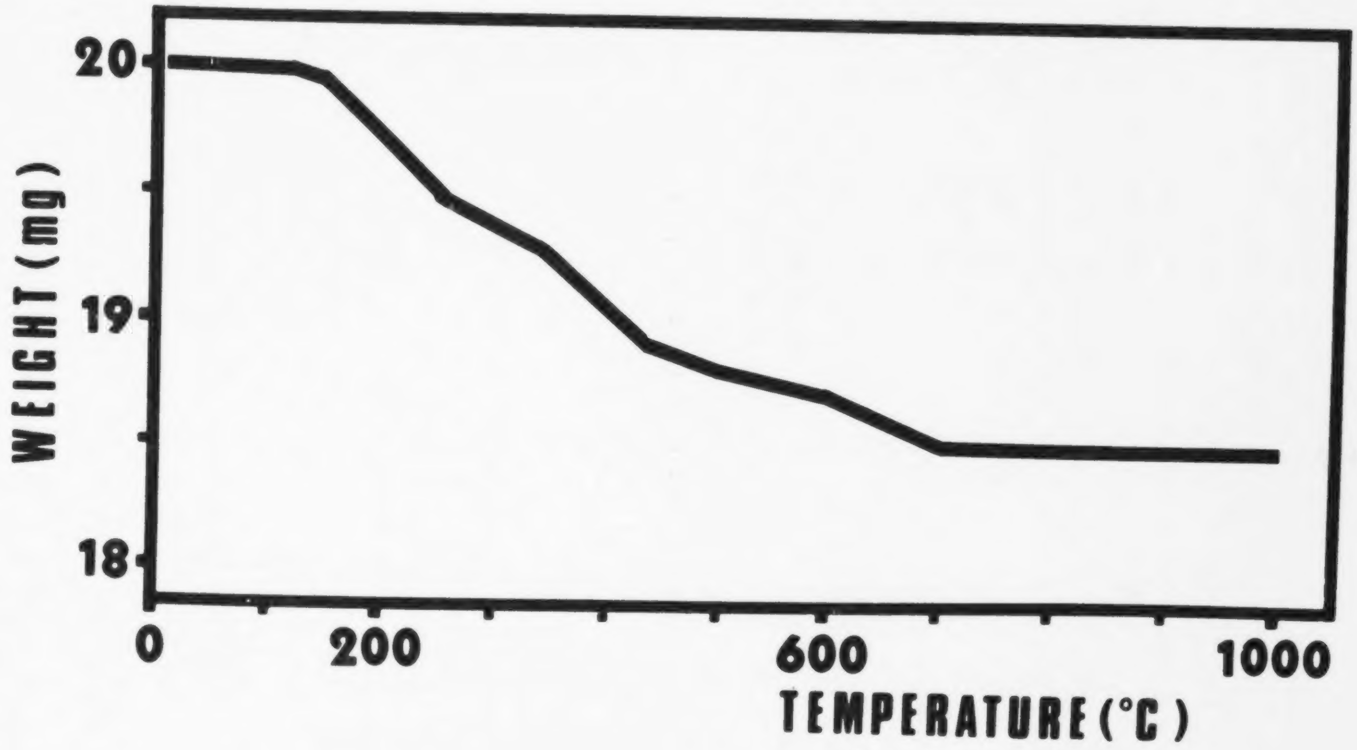
ANALYSIS OF PARTICULATE ADSORBED COMPOUNDS USING THE COMBINATION OF THERMOGRAVIMETRY AND MASS SPECTROMETRY

BY

G.M. Cornetti - FIAT Research Center
Torino, Italy

A. Di Lorenzo - Laboratorio di Ricerche
sulla Combustione, CNR,
Napoli, Italy

Thermogravimetric curves of soot samples collected at 80 cm from the burner



Next slide, please. #7

This slide shows the instantaneous mass spectrum of soot collected from the burner related to the higher mass electron ratios, using the ionizing energy at 70 electronvolt. The spectrum shows clearly that compounds with high molecular masses are associated with soot; the most prominent masses are 350, 374, 398, 400, 424, 448, 472, corresponding to the compounds benzocoronene, benzobisanthrene, ovalene dibenzocoronene, tribenzocoronene, tetrabenzocoronene, tetrabenzoperopyrene.

Of course, vaporization under high vacuum does not separate the components of the mixture and deliver them one by one to the mass spectrometer, as gas chromatography does. Nevertheless, the ability of the on-line computer to store and easily manipulate the spectra taken during the analysis can help to obtain a quantitative evaluation.

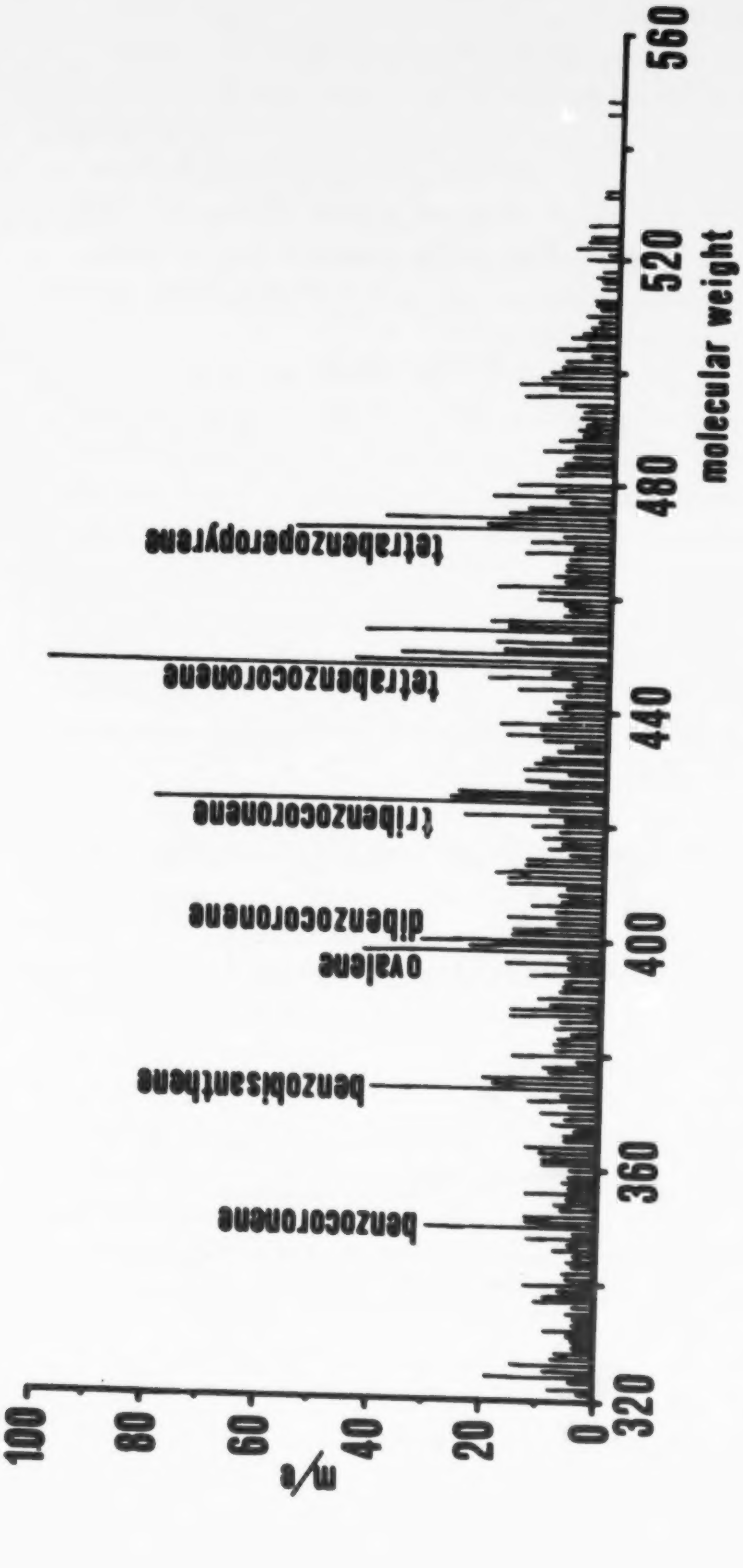
It is important to note that in this analysis the heating rate, at the moment manually controlled, was about 40 degrees Centigrade per minute. When the probe can be heated with an automatically controlled temperature program, a more acceptable separation of compounds will be possible.

In addition, bearing in mind that the mass spectra of unsubstituted PCAH consists of a very intense molecule ion accompanied by a very few weak fragment ions, quantitative determination of some sample components in soot is also permissible.

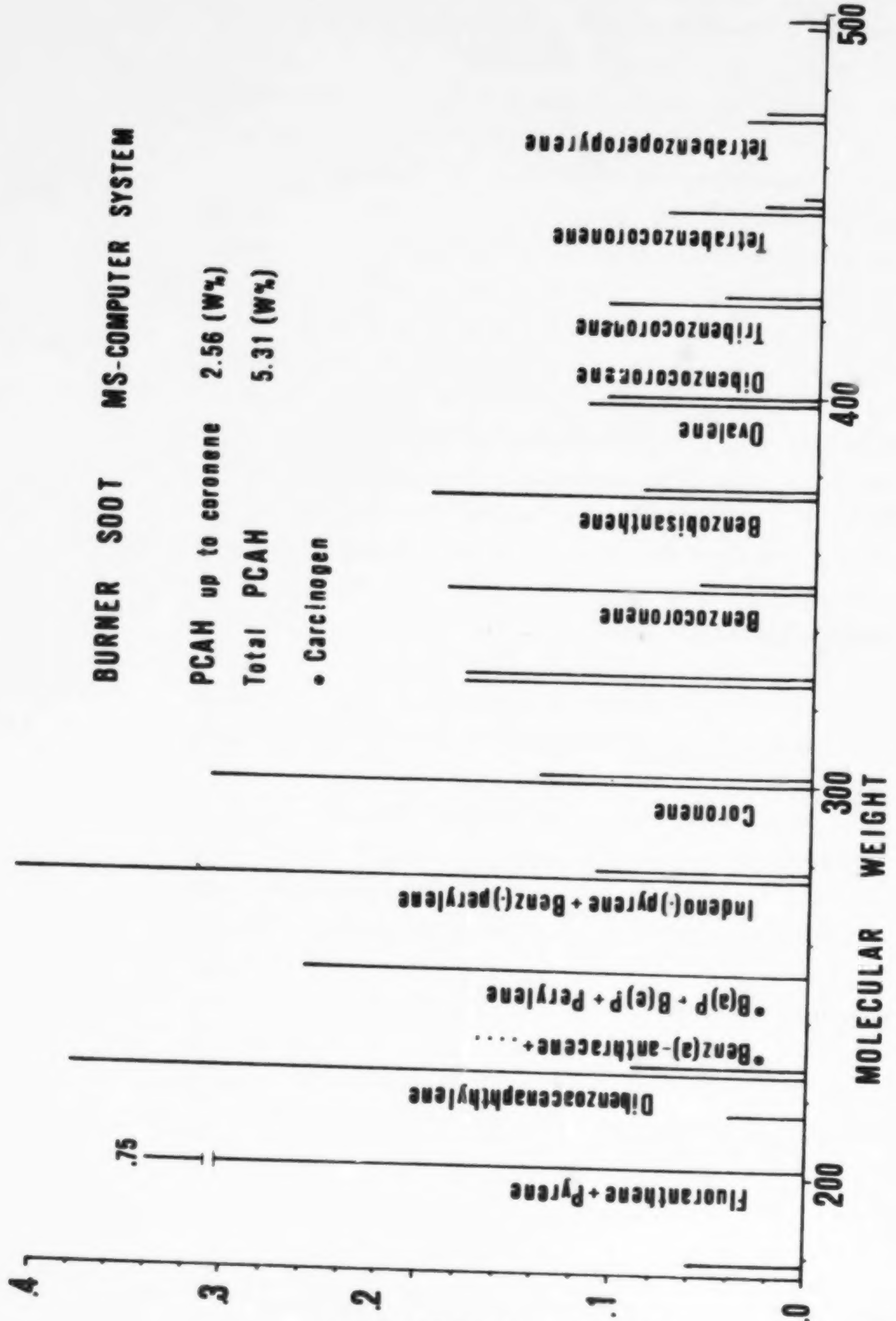
To calibrate the molecular ion areas, we have used the weight percentage in soot of fluoranthene plus pyrene, molecular ion 202, determined by gas chromatography.

Next slide, please. #8

The detailed weight percentage of the polycyclic aromatic hydrocarbon in soot of the burner, thus evaluated, are reported in this slide. The sum of other relatively abundant peaks, in the mass range of 316 to 198, determined by excluding ions attributed to fragments and ions not attributable to polycyclic aromatic



INSTANTANEOUS MASS SPECTRUM


BURNER SOOT MS-COMPUTER SYSTEM
PCAH up to coronene 2.56 (W%)
Total PCAH 5.31 (W%)
• Carcinogen
Fluoranthene+Pyrene
.75
Dibenzoacenaphthylene
•Benz(a)-anthracene+....
•B(a)P+B(e)P+Perylene
Indeno(·)pyrene+Benz(·)perylene
Coronene
Benzocoronene
Benzobisanthene
Ovalene
Dibenzocoronene
Tribenzocoronene
Tetrabenzocoronene
Tetrabenzoperopyrene
.0
.1
.2
.3
.4
WEIGHT PERCENTAGE
200
300
400
500
MOLECULAR WEIGHT

hydrocarbons is also reported. Right at the top of the figure, we give the amount of polycyclic aromatic hydrocarbons up to coronene and the total polycyclic aromatic hydrocarbons.

It may be noted that the total amount of polycyclic aromatic hydrocarbon up to coronene represents about half the total polycyclic aromatic hydrocarbons detected by the MS computer system

Next slide, please. #9

The values of the total amount of polycyclic aromatic hydrocarbons up to coronene and the total polycyclic aromatic hydrocarbons detected by the MS computer system are presented in this slide, together with those of the total polycyclic aromatic hydrocarbon determined by gas chromatography and the weight loss percent by thermogravimetry up to 550 degrees Centigrade.

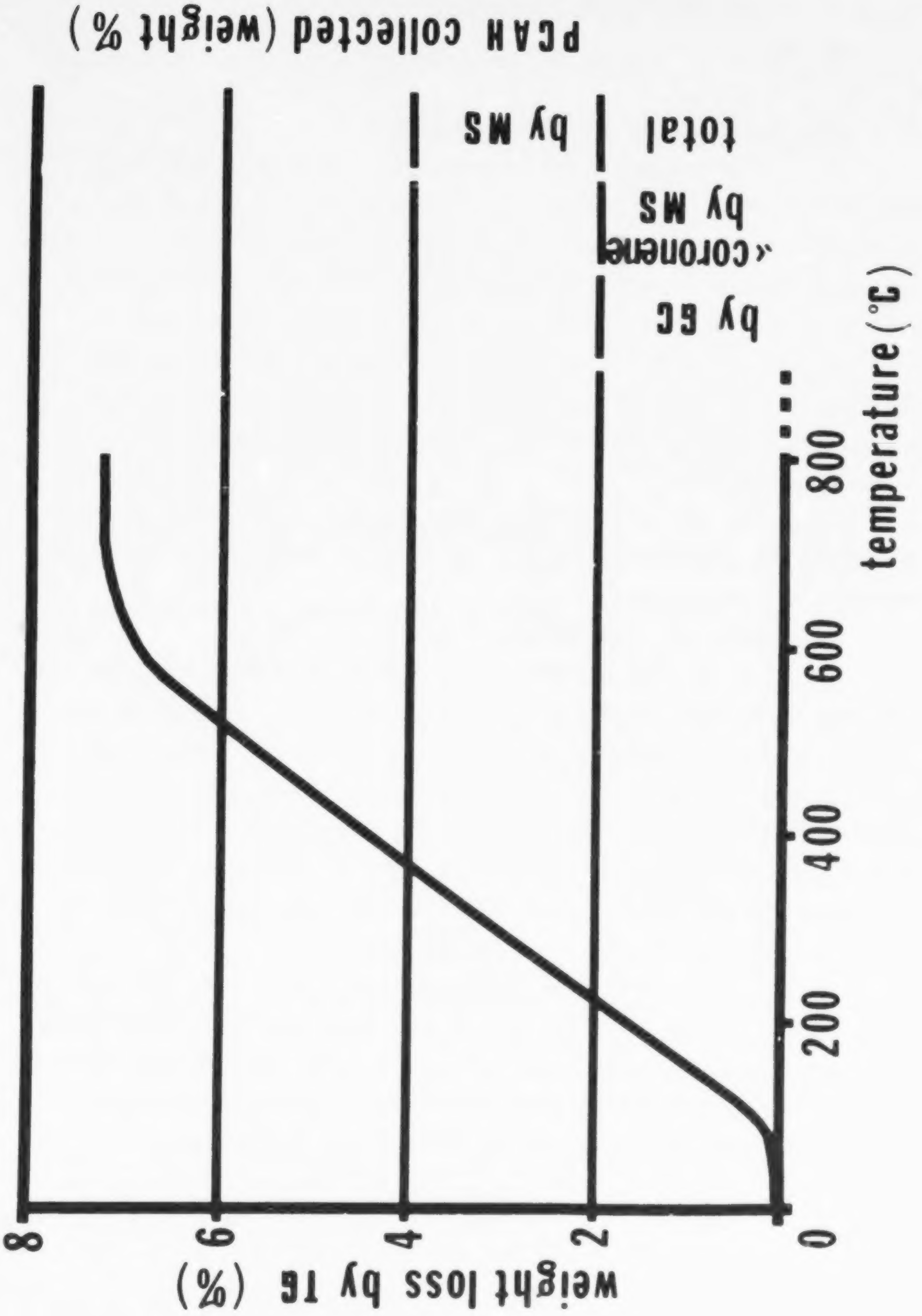
The agreement between the calculated polycyclic aromatic hydrocarbons up to coronene by MS and the GC value is quite good. Similarly, bearing in mind that ions not attributable to PCAH are not calculated. The material balance between the weight loss of soot determined by thermogravimetric curves and the total amount of PCAH analyzed by MS computer system is consistent.

The thermogravimetric curves of soot samples show that the compounds determined by previous procedure represent only a fraction of the volatile part associated with soot. Relating to the polycyclic aromatic hydrocarbon present in the soot, the mass spectrometric analysis clearly shows the presence in soot of numerous PCAH with molecular mass beyond coronene, which was previously the highest molecular weight PCAH found in soot and in polluted air.

The use of thermogravimetry and mass spectrometry data reduction system ensured the consistency of the analysis by a check on the material balance between the weight loss of soot determined by thermogravimetric curves and the quantities of volatile products analyzed by mass spectrometry and determined by the computer.

Thank you so much for your attention.

MS-computer and GC data compared with TG results



MR. HURN: Thank you, Mr. Cornetti.

(Brief recess)

Well, let us get under way again, gentlemen, this time edging ever closer to control technology. Ed Barry has some information for us on particulate studies at Mobil.

Mr. Barry.

MR. BARRY: Thank you very much, Dick.

As many of you may know, about a year and a half ago, Mobil published a study concerned with the availability of diesel fuel as we saw the need might arise; and at that time, our concern was from the point of view of building grass roots refineries and, also, the effect of varying fuel quality on heavy duty diesel emissions.

We subsequently re-looked at this regarding modifying existing refineries, and we will be presenting a paper at the upcoming API meeting in Toronto about increasing diesel fuel supply with existing refineries.

Following our work on heavy duty diesels, we focused on the impact of the light duty diesels, not only on the gaseous emissions, but also the particulates.

May I have the first slide, please? #1

Our program, very briefly, uses a dilution tunnel sampling technique. We are interested in both the emissions as well as the reliability of the method. We are interested in the analysis for particulates and, also, particulate size distribution because we feel we need to be able to put some perspective on the question of what happens here when emissions vary. Two of the areas that should be covered in the type of study are the fuel composition, which is of concern to us, and also, the engine type.

In our prior study with the heavy duty engines, we did look at four types of engines; and we did find that the variability among the engines was extremely large and in all cases much larger than we could affect by changes in fuel consumption. We are planning to conduct the same type of study but using light duty diesels.

PARTICULATE EMISSION

LIGHT-DUTY DIESEL VEHICLES

PROGRAM

USING A DILUTION TUNNEL SAMPLING TECHNIQUE, THE PROGRAM WILL INCLUDE:

- TEST METHOD RELIABILITY
- ANALYSIS FOR TOTAL PARTICULATE AND PARTICULATE SIZE DISTRIBUTION AS RELATED TO:
  - VARIABILITY WITH ENGINE TYPE
  - VARIABILITY WITH FUEL COMPOSITION

Could I have the next slide, please. #2

Touching briefly on each phase, on the method reliability, work items include exhaust line length and geometry and the consible aerosol correction, which I have called here (as Merril Korth mentioned this morning) using the two hot FID analyses, one before and one after the filter.

We are also interested in the effect of sample probe location and also filter holder temperature.

May I have the next slide, please. #3

This is a technical list of the type of equipment we have installed. Most of you have worked with it before. Flame ionization for hydrocarbons, we are using a Selesco light extinction smoke meter, and I will touch on that in a moment; NDIR for CO_2, CO; chemiluminescent for NOx, dilution tunnel; a Rack Stack Master for the gas meter, and our filter holder and an electrical aerosol analyzer for the particle size distribution.

This is something that has rather intrigued us because in the heavy duty engines concern's with smoke opacity; looking at the smoke opacity and total particulates on a few light duty engine tests, we have noticed that several times as our smoke opacity goes down, our total particulates go up and vice versa. So, we feel that there is something to be learned from our point of view, of what happens in relationship between smoke as seen, particle amount and size.

May I have the next slide, please? #4

I know you must feel that you have had it with dilution tunnels. I did not realize there were going to be so many pictures of them today, or I would have omitted this slide. It is another one, the same type. We can sample (here) the raw exhaust in the tunnel. We used the Selesco smoke meter (here) directly to measure the opacity of the smoke.

We have done some work with the filter holder, outside the tunnel, We will now put it inside to see what effect that has.

METHOD RELIABILITY

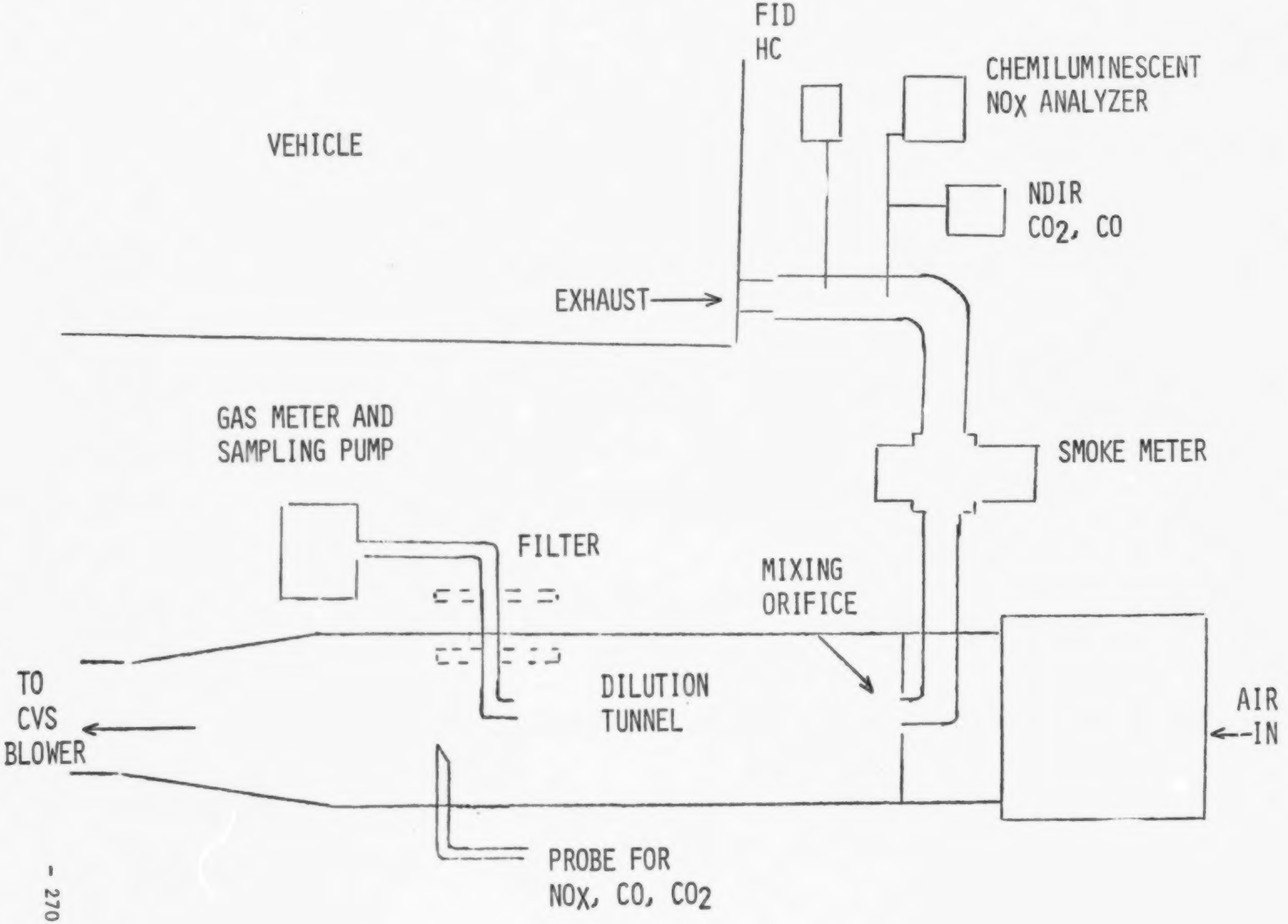
WORK ITEMS INCLUDE:

- EXHAUST LINE LENGTH AND GEOMETRY
- CONDENSIBLE AEROSOL CORRECTION (PROPOSED EPA TEST METHOD)
- SAMPLE PROBE LOCATION IN TUNNEL
- FILTER HOLDER TEMPERATURE

INSTRUMENTATION AND APPARATUS

COMPONENT	INSTRUMENT	MANUFACTURER
HYDROCARBONS (PPM)	HEATED FLAME IONIZATION DETECTOR	BECKMAN MODEL 402
SMOKE OPACITY (%)	LIGHT EXTINCTION SMOKEMETER	CELESCO/BERKLEY MODEL 107
CO_2	NON-DISPERSIVE INFRA-RED SPECTROPHOTOMETER	BECKMAN MODEL 215
CO	N.D.I.R.	BECKMAN MODEL 215
NO_X	CHEMILUMINESCENT ANALYZER	
PARTICULATES	DILUTION TUNNEL	-
	GAS METER, VACUUM PUMP	RAC STAKSAMPLER MODEL 2343
	FILTER HOLDER	MILLIPORE
	ELECTRICAL AEROSOL ANALYZER	TSI COMPANY

SCHEMATIC OF EXHAUST SAMPLING EQUIPMENT



May I have the next slide, please? #5

I would like to apologize for the quality of the picture, but I include it because I would like to focus your attention on one of the areas we feel may be important.

In diesels, we make rather simplistic, but key, definitions; we talk about direct (DI) and indirect (IDI) engines. These types (DI) are very similar to the heavy duty engines that we looked at before; but on the light duty passenger cars and vehicles, most of them, referred to today, are indirect injection types. (IDI types).

There are two. Mercedes Benz has one type, and Ricardo, we have heard about this morning, has the other. We plan to look at both types. Note, each has a small chamber ahead of the main combustion chamber. The fuel is initially injected here, the ignition starts, and proceeds out. In this case (Ricardo), the fuel is injected somewhat at an angle; and I would refer you not only to papers by Ricardo, but to a paper recently given by General Motors on the effect, for example, of the placement of the injector, the angle and its effect on gaseous emissions and economy.

Regardless, there are two different types of indirect engines, and we feel both should be looked at to see if there is a difference in performance and emission.

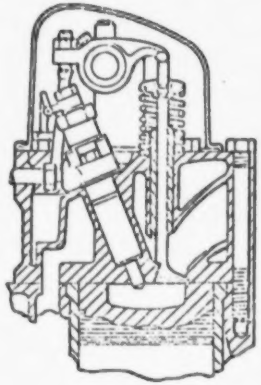
May I have the next slide, please? #6

Currently, we are testing for driveability and general performance, a Volkswagen Rabbit, an Opel 2100-D, a Mercedes 5-cylinder, and the Oldsmobile 350. This particular car (Opel) is not sold in the United States; we ordered it in Germany. It is one of the first ones we had and has a Ricardo type precombustion chamber. We were able to run direct comparisons between the Mercedes type and the Ricardo type precombustion chambers. We have now added the Volkswagen diesel and the Oldsmobile. These four types of vehicles will be used on our study of fuel effects and particulate emission.

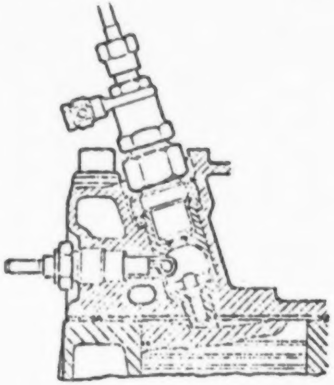
May I have the last slide, please? #7

The last slide is a brief look at exactly what we will be evaluating from the fuel side. We are interested, for example, in

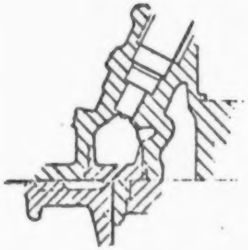
COMBUSTION CHAMBER TYPES



DIRECT INJECTION



MERCEDES-BENZ 180D
COMBUSTION CHAMBER



RICARDO AIR CELL (MARK V)
COMBUSTION CHAMBER

INDIRECT INJECTION

DIESEL CARS

	VOLKSWAGEN	OPEL	MERCEDES	OLDSMOBILE
VEHICLE WEIGHT, LBS.	2250	2800	3450	4150
ENGINE MODEL	DIESEL	2100D	OM617	350 DIESEL
CYLINDERS	4	4	5	8
DISPLACEMENT, L	1.5	2.1	3.0	5.7
BORE, MM	76.5	88	91	103.1
STROKE, MM	80	85	92.4	86.1
POWER, HP	50	60	77	120
a RPM	5000	4400	4000	3600
COMBUSTION CHAMBER TYPE	COMET	COMET	PRECHAMBER	COMET

TEST FUELS

PHYSICAL PROPERTY VARIATIONS INCLUDE:

- VOLATILITY
  - NO. 1D VS. NO. 2D
  - TAIL END VOLATILITY, U.S. (640°F @ 90%) VS. EUROPEAN (680°F @ 90%) TYPE
- CETANE NUMBER
  - FROM 55 DOWN TO 35
  - USE CETANE NO. IMPROVER ADDITIVE TO RAISE 35 CETANE NO. FUEL TO MINIMUM LIMIT OF 40

comparing a No. 1-D and a 2-D fuel. I believe reference was made this morning to various 2-D fuels, and someone referred to a Jet-A type fuel. That is a kerosene type fuel very similar to a No. 1-D.

There is another distinction I would like to bring out; and that is, there are two general types of diesel fuels sold; one in the European market, one in the U. S. market. In general, the fuels sold for diesel engines in the European market have a slightly higher tail end boiling point than in the U. S.

To the best of our knowledge, these are performing entirely satisfactorily; so we intend to make a comparison between these type types of fuels. Cetane number as a measure of ignition delay has been mentioned as a variable. We intend to study ranges from 55 down to 35. We chose this number because, currently I believe, you might correct me Dick (Hurn), the Bureau of Mines survey looks at about 44 or 45 as the average cetane number today; so 55 would be considered quite high. Generally, the ASTM refers to 40 as a minimum cetane number; so we feel that we should get significantly below that to see the effect. Also, I think, another question has to be answered. For example, many refiners are effectively using additives to improve the cetane number. These are generally either amyl nitrate or mixed hexyl nitrates. So, another phase of this study will be to actually take these low cetane fuels and raise the cetane number up to minimum level of 40 and perhaps slightly higher with the cetane number improvers to determine what effect this would have on particulate emission.

Gentlemen, that is a thumbnail sketch of the program and the type of variables we intend to look at. At the conclusion of the session, I would be glad to answer any specific questions you might have. Thank you very much for your attention.

MR. HURN: Thank you, Ed. We will look forward with keen interest to what you further develop.

Now, we can head right into our meal of information, addressing directly controlled technology and what people are doing and think we might be able to do. The first of these following three papers by Karl Springer of Southwest Research Institute, to tell us of their work in exhaust particulate trapping.

Karl.

MR. SPRINGER: We can go ahead with the first slide. #1

What I will be doing is repeating the gist of an SAE meeting paper that was given in Milwaukee. I doubt if very many of you were there; and, to my knowledge, it still represents the major amount of information regarding the trapping and after treatment of diesel particulates in its complete sense. In other words, not just the removal of particulate itself, but any other effects that might have occured.

(Problem with slides)

MR. HURN: All right, is Jorgen Birkland — Jorgen, this might be an opportune time. There have been some developments recently, that have to do with the acceptance, I guess you might say, of emission responsibility or interest in the federal agencies. DOE has expressed interest; and, as it now develops, it appears that the Power Systems Division under the Energy Technology Directorate within the DOE may be doing work in this area.

Jorgen Birkland is in the Power Systems Division and will tell you something of what he sees developing there.

MR. BIRKLAND: Thank you, Dick. I am elected, I guess, not having slides, and not having a whole lot to say at this time.

As a result of recent meetings between DOT and EPA and Department of Energy, we will probably be starting the program focusing on the diesel particulate emission problem. We are in the process right now of coming up with a detailed program plan — Dick Hurn is intimately involved in doing that — and for those of you from universities who are reaching into your markets and starting to write proposals now, I want to say that we are also identifying

REMOVAL of EXHAUST
PARTICULATE
from a
DIESEL CAR

the source of funds to do this within the Division and what the amount will be.

We do not have final answers on that, yet. The program will focus on the topics that I think John Johnson very accurately described, the areas of the engine and fuel injection modification, the areas of some research opportunities there. We will not be looking at some of the killing animals and bacterialand whatnot, or on modeling plumes or some of the other aspects.

We will be lookingaat modifications, or control technology; but things that are really coming from in cylinder control. I really do not have anything else I can say on that right now.

Thank you.

MR. HURN: Thank you, Jorgen. I believe I can say that it looks very promising for development of at least an interagency coordination in the effort on diesel emissions, diesel particulate, in particular, possibly this coordination somewhat better than we might have seen in some cases in the past. I think those of us in DOE are dedicated to bringing this to happen, and I myself will be approaching the more active players in the game to see if this does happen in the very near future.

MR. SPRINGER: We have heard this morning a number of times #2 what the problem is; and, to reiterate, the problem is that diesel particulate is too small and too light and there is also too much of it, and that is really the problem that the designer faces in trying to come up with after treatment approaches.

For example, when I speak about too much, I mean almost 100 pounds and on the order of 168 gallons is produced during 100,000 miles from a car such as a mercedes 300D. That works out to be something like 35 gallons for every 20,000 miles.

Next slide. #3

That is more than one gas tank full of particulate for every 20,000 miles. Our object in the work that we did was to have at

'THE PROBLEM'

★TOO SMALL - LIGHT

50% < 0.5 micron

★TOO MUCH

100 k mi. - 92 lbs.

168 gal.

OBJECT

Reduce Particulate

by 50 % +

using lead traps !

least a 50 percent reduction in particulate and the approach was to take available lead-trap technology; those of you may remember there was a lot of work done to remove lead particulate from cars fueled with gasoline containing tetraethyl lead.

Next slide. #4

This describes the vehicle that has already been described by previous talks today, the 5-cylinder Mercedes 300-D with automatic transmission at the 4000 pound weight.

Next slide. #5

The plan was in three separate segments. The first was to identify the method that was best from the lead trap approaches that had been tried on gasoline cars. The next was to look at not only what did it do to particulate after we selected the best method, but to see what it did to unregulated pollutants and other things besides particulates. Then, finally, do some work on its durability to see how long it will last before it plugged up.

Next slide. #6

One of the things that we did before we started any of our screening experiments and one of the things that made us have a much different viewpoint on how to collect particulate, was to drive the different cycles; for example, the federal test procedure, the city cycle and the highway fuel economy cycle. We wanted to drive these two cycles on the highway and measure the max, min, and average exhaust temperatures that came out of the manifold of the engine, as well as that that went into the rear muffler of the vehicle.

The rear muffler is located adjacent to the fuel tank, and you can see that the average temperatures — this is in degrees Centigrade — are extremely low compared to what you might have expected from a diesel engine. These are cool running engines, and this makes a lot of difference on what you can do in the way of collecting or possibly burning materials off or reacting materials once they are collected. So, keep in mind these temperatures. The average temperatures are rather low. They are higher for the fuel economy type test, which is approximately 48 mile an hour average speed.

MERCEDES 300D

- ★ 1975
- ★ 5 cyl
- ★ 3 litre
- ★ 21:1 CR
- ★ 77 hp
- ★ auto trans
- ★ 5038 mi
- ★ 4000 lbs

TEST PLAN

1. Identify Best System
2. Evaluate Effects
3. Determine Durability

ROAD TEMPERATURES, °C

	max	min	avg
★ FTP			
Manifold	544	120	190
Rear in.	316	129	164
★ FET			
Manifold	516	128	275
Rear in.	303	150	210

The rear inlet, where the final muffler device was to be located is, of course, cooler than the manifold, which is right at the exhaust manifold of the engine. Only occasionally would you get to the maximum temperatures that you see here, say 544 degrees Centigrade. This only occurs during the big acceleration up to 56 miles an hour; so, it happens only once during the whole test.

Next slide. #7

We brought the vehicle in from the road and to simulate the cooling effect of the road, we not only used the normal EPA fan, but we had to close the hood, which is different than the way the test is normally run for emissions purposes, and added a number of supplemental blowers that we could position under the car to simulate the effect of the road temperature profile.

Next slide. #8

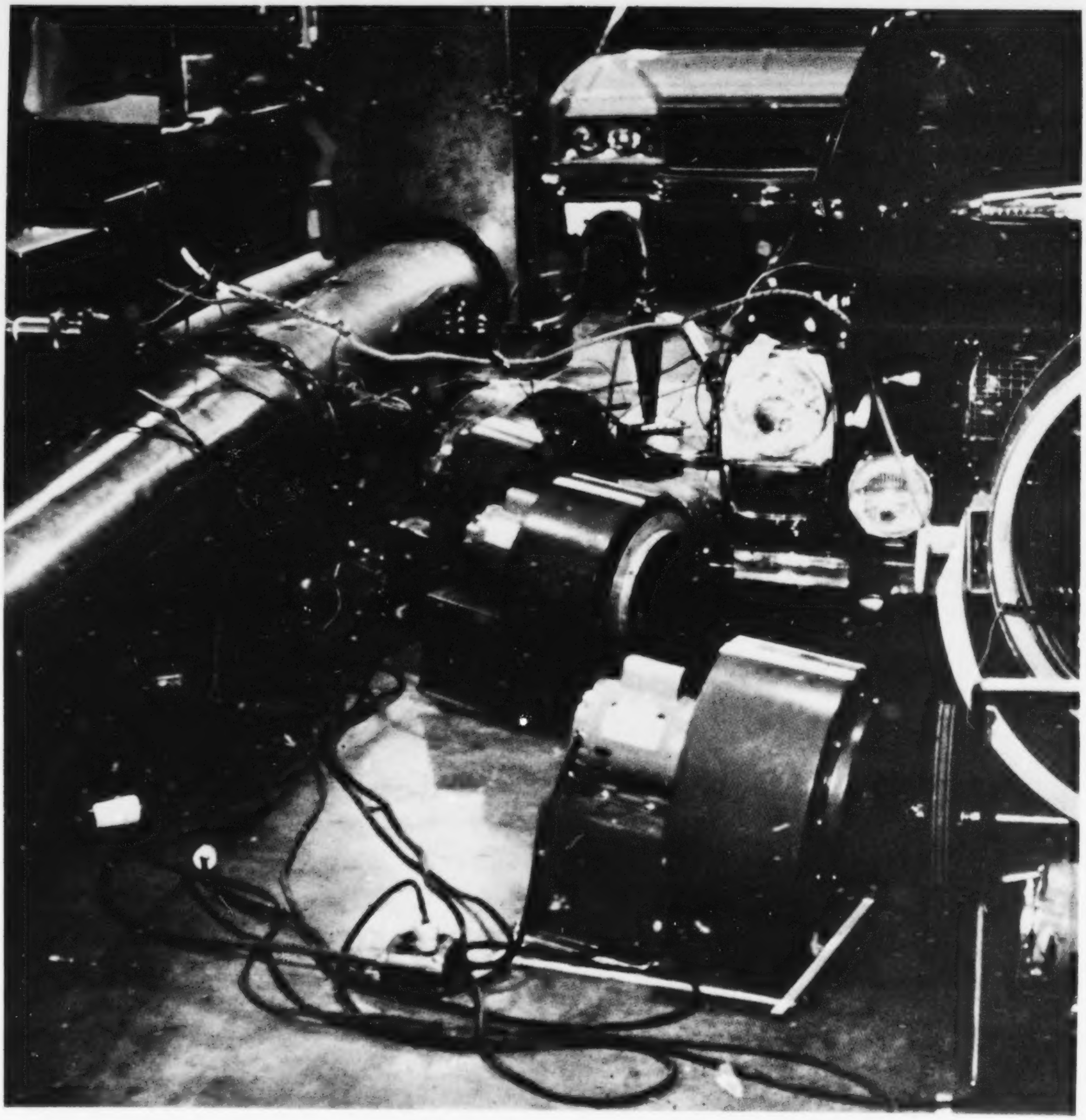
This shows the controls; a lot of this was manually done because we would adjust our configurations, and we had to have a tremendous amount of flexibility. This is part of a dilution tunnel that you see between the man and the vehicle and the dilution air came in through the dilution box at that point.

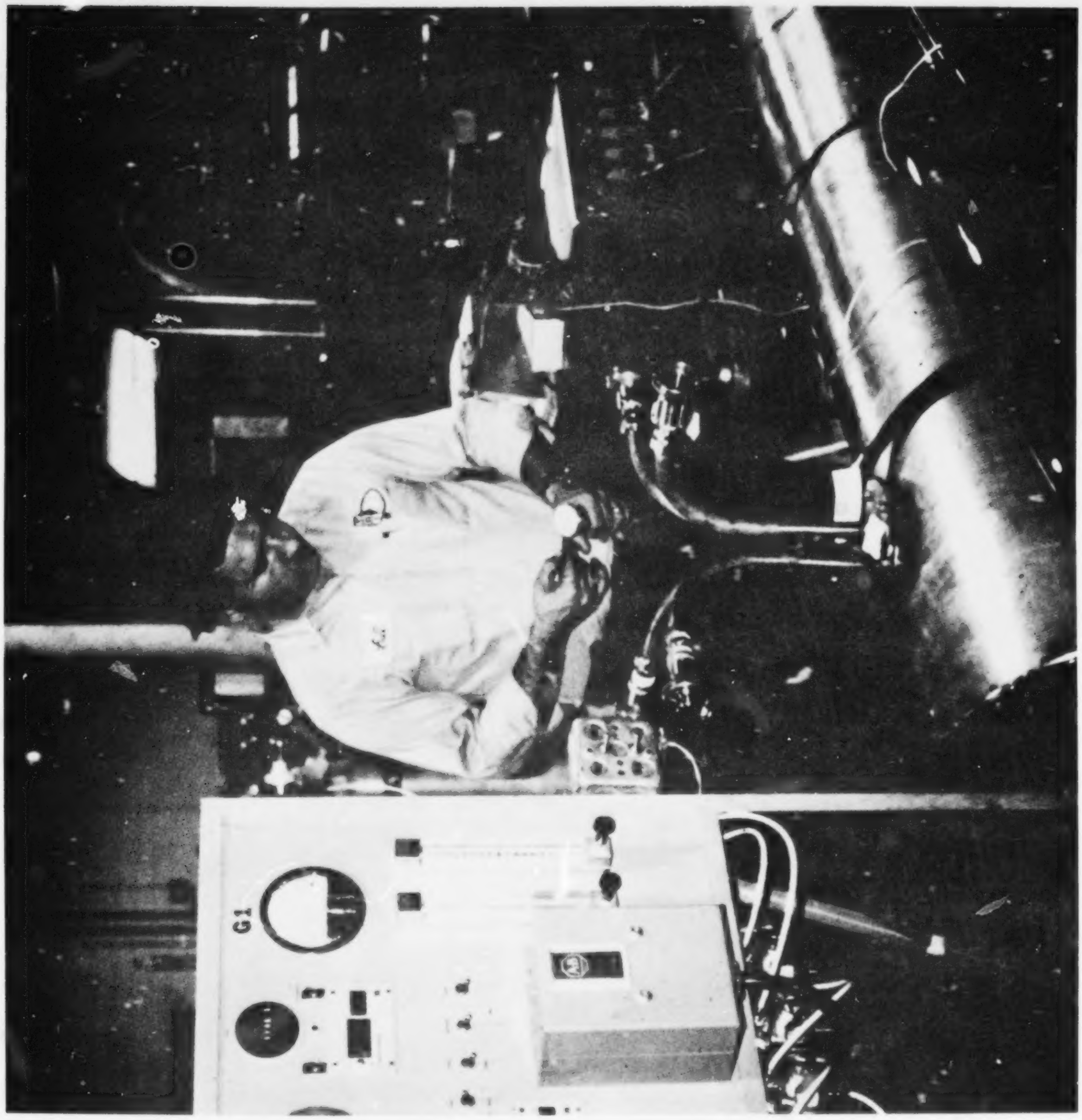
Next slide. #9

This will show another view of the tunnel. Again, this is the make-up air that goes through the system for purifying the air, taking the particulate out of it. The total exhaust of the vehicle is entered at this point, and the next slide will show the man #10 loading a filter for one of the probes. There are four of these probes that go down into the tunnel and face into the flow. So, the exhaust is coming down the tunnel like so.

Next slide. #11

To screen a number of configurations,— we did some 48 different configurations, some 367 tests in the screening and evaluation part of the project — we located the equipment exterior to the vehicle. In other words, this would be the front of the car, an and we brought the exhaust out from the side.

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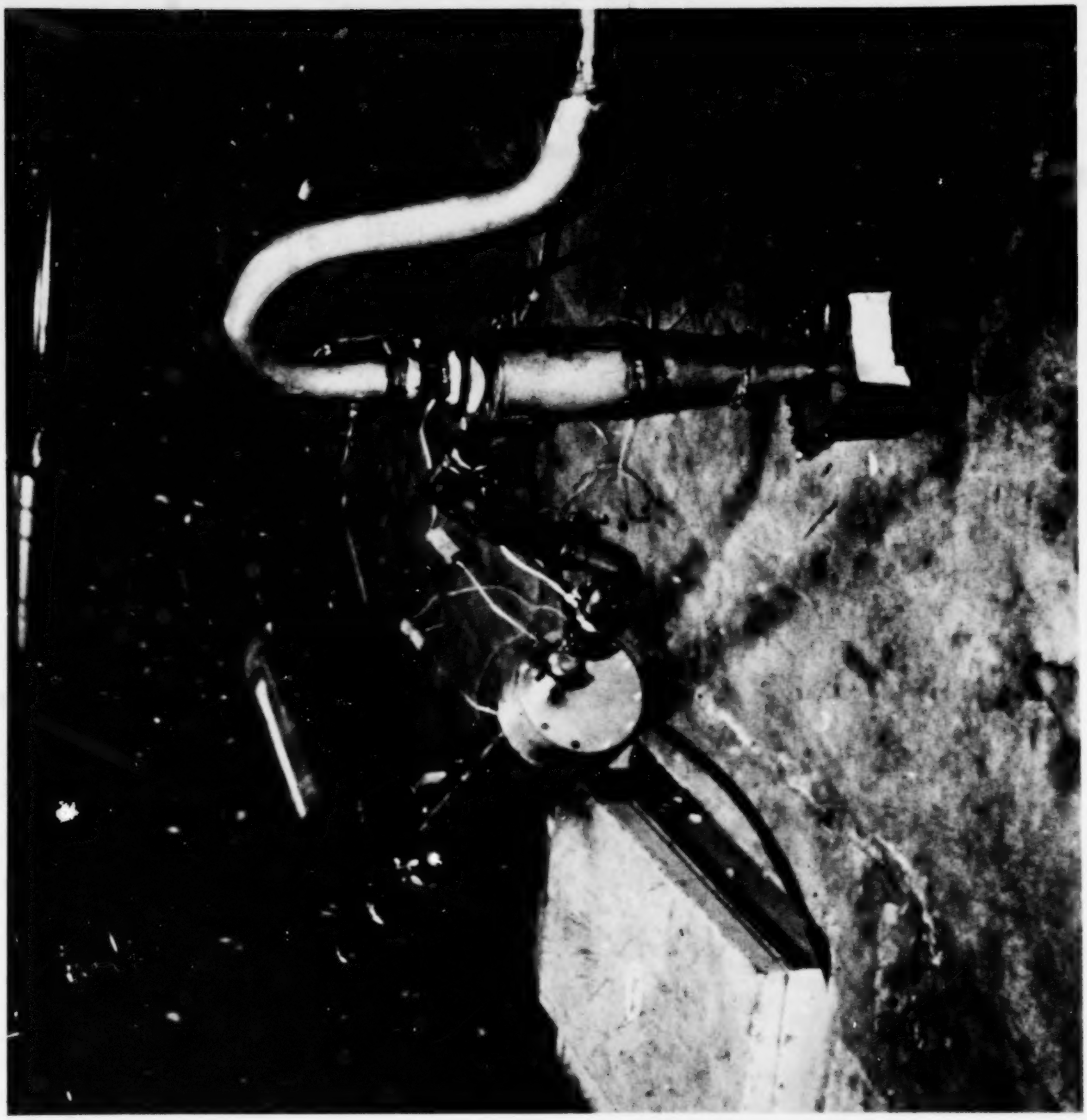


This is an agglomerator device; we will talk some more about it. Everyone realizes that this is a simple cyclone; and I can tell you at this point that the simple cyclone still does not work on diesel particulate. It never has, and it still does not.

Next slide. #12

That is one of the first things we put into our junk pile. The next item that we tried was a different type of a separator device; and our whole theory in doing this project was that, like lead, to get lead to separate, there was a desire to agglomerate it. The idea here was to take the very fine, very light, particles and somehow make them bigger, make them heavier, so that we could effect some type of separation by an inertial device.

Then, of course, the third item would be some place to put all this particulate. Certainly you would need, if you only collected half the particulate, in 20,000 miles, you would need a tank about the size of a 20 gallon fuel tank. We did not worry about the collection volume at this point until we could even separate it.

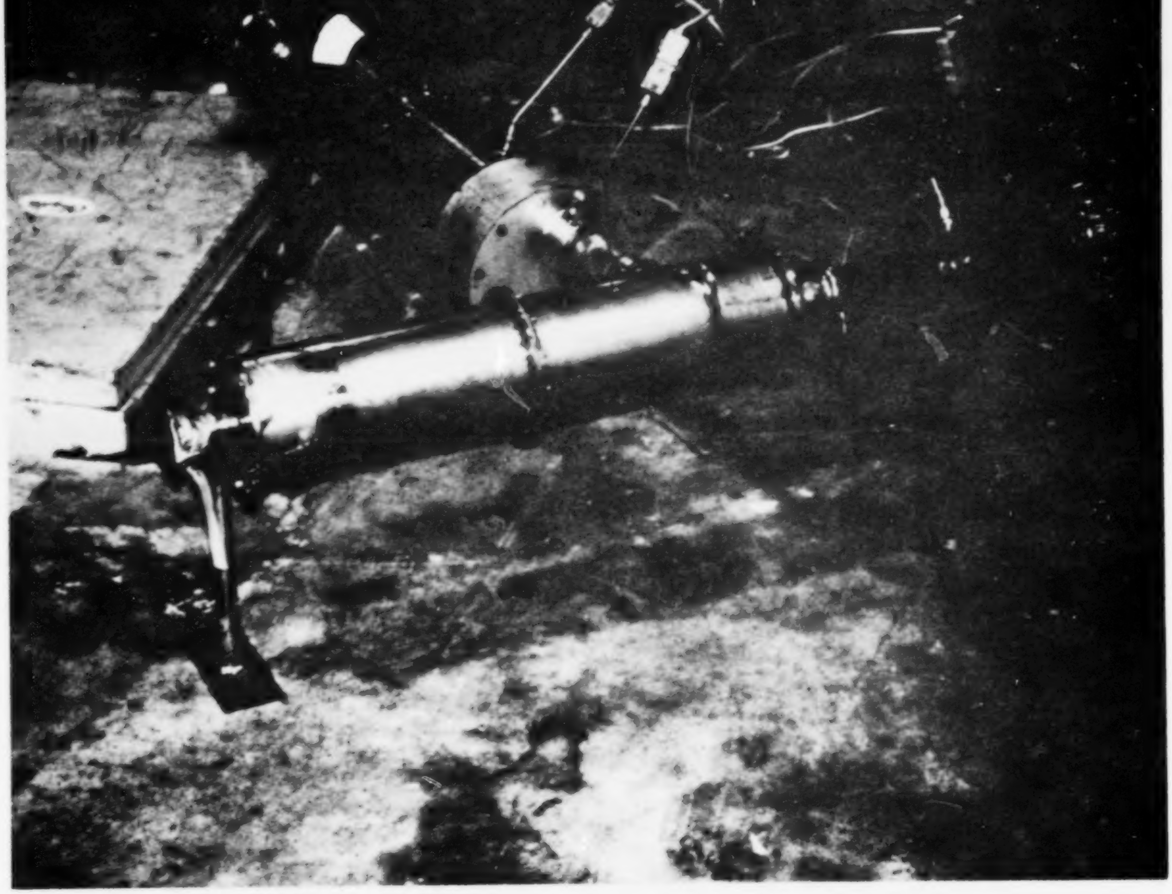
So, this device was supposed to agglomerate, make the particles bigger and heavier. This device, which is the Ethyl Corporation tangential anchored vortex, a high technology inertial separator, was intended to separate the particles once they were made bigger and heavier.

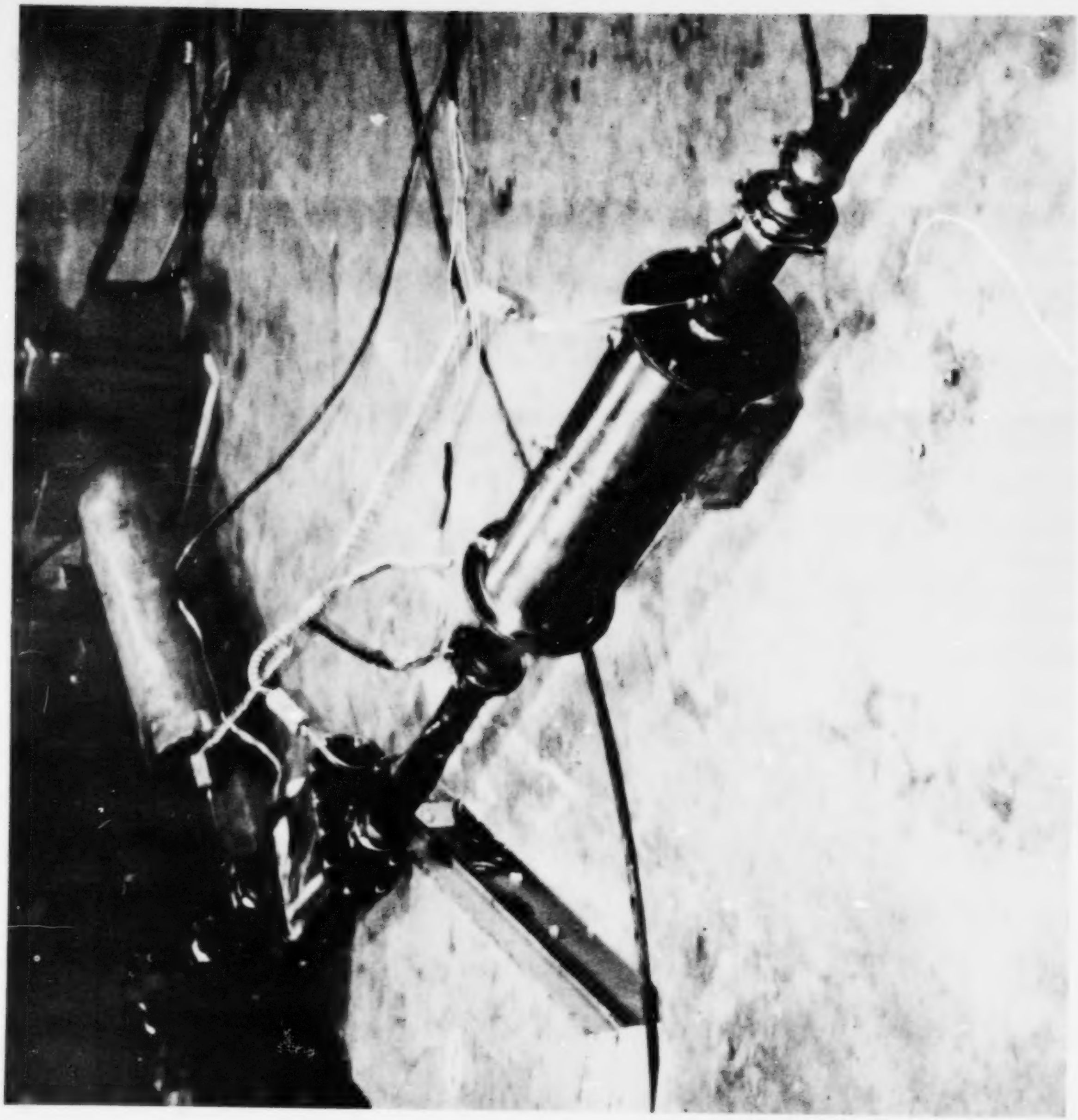
Next slide. #13

This is the same rear agglomerator that would take the place o of the rear muffler. This is a smaller agglomerator that we put in series. We call this the front agglomerator, and this is the rear one; we will talk some more about that in a moment.

Next slide. #14

In our screening test, we found that, when we used that large cylindrical agglomerator, the largest one of the two,we just saw in the previous slide, when it was brand new, we got only a third of the particulate from the vehicle. In other words, we collected two-thirds of it; and this was quite amazing and the





FTP COLLECTION EFF.

	%	ΔP
AIR new	66	30
AIR, TAV	53	143
AIF new	25	14
AIF, AIR	64	70
AIF, TAV	41	99
AIF, AIR, TAV	49	170

pressure drop,— this is in millimeters of mercury — was 30 m millimeters at this point, when the unit was new.

We tried the tangential anchored vortex with it, and as this original agglomerator became more used, the more we operated with it, efficiencies kept dropping. Now, this is the front agglomerator, the small one; and it never did have a lot of efficiency, but it did not have a lot of volume, either. Really, what was happening was that those agglomerators were not acting the way we wanted them to work; they were acting strictly as a trap.

All the voids within the agglomerator were actually just filling. When we completed all our selection tests and decided on a system, which was this front agglomerator, the small one, the large cylindrical one, and a separator, we were still obtaining about a 50 percent reduction. Our target was met sufficiently to go into an evaluation step and a durability step.

The back pressure is of concern. A good bit of the back pressure is due to the tangential anchored vortex, because to get high inertial separation velocities which we thought were necessary, you have to do work on the gas.

Next slide. #15

This shows the interior material when it was new. This is made by the Texaco alumina process. The alumina has been deposited on something similar to a Brillo pad. It is steel wool. It is dipped in alumina, then fired at 1000 degrees Fahrenheit to grow the crystal structure. This does not have an active catalyst on it. It is just alumina on steel wool.

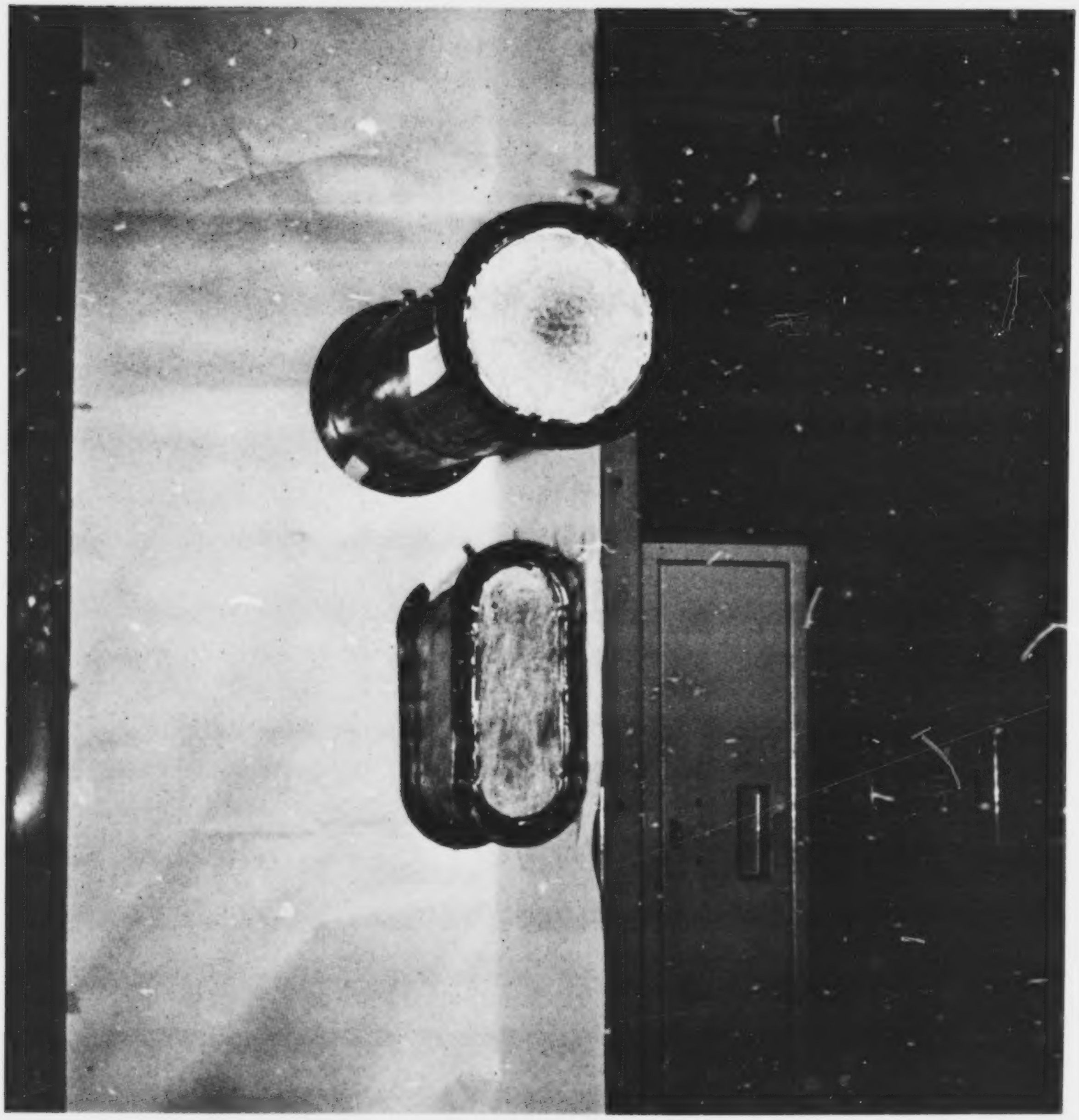
This is the front unit, again. This is the rear unit. This is the unit that made the big improvement in particulate.

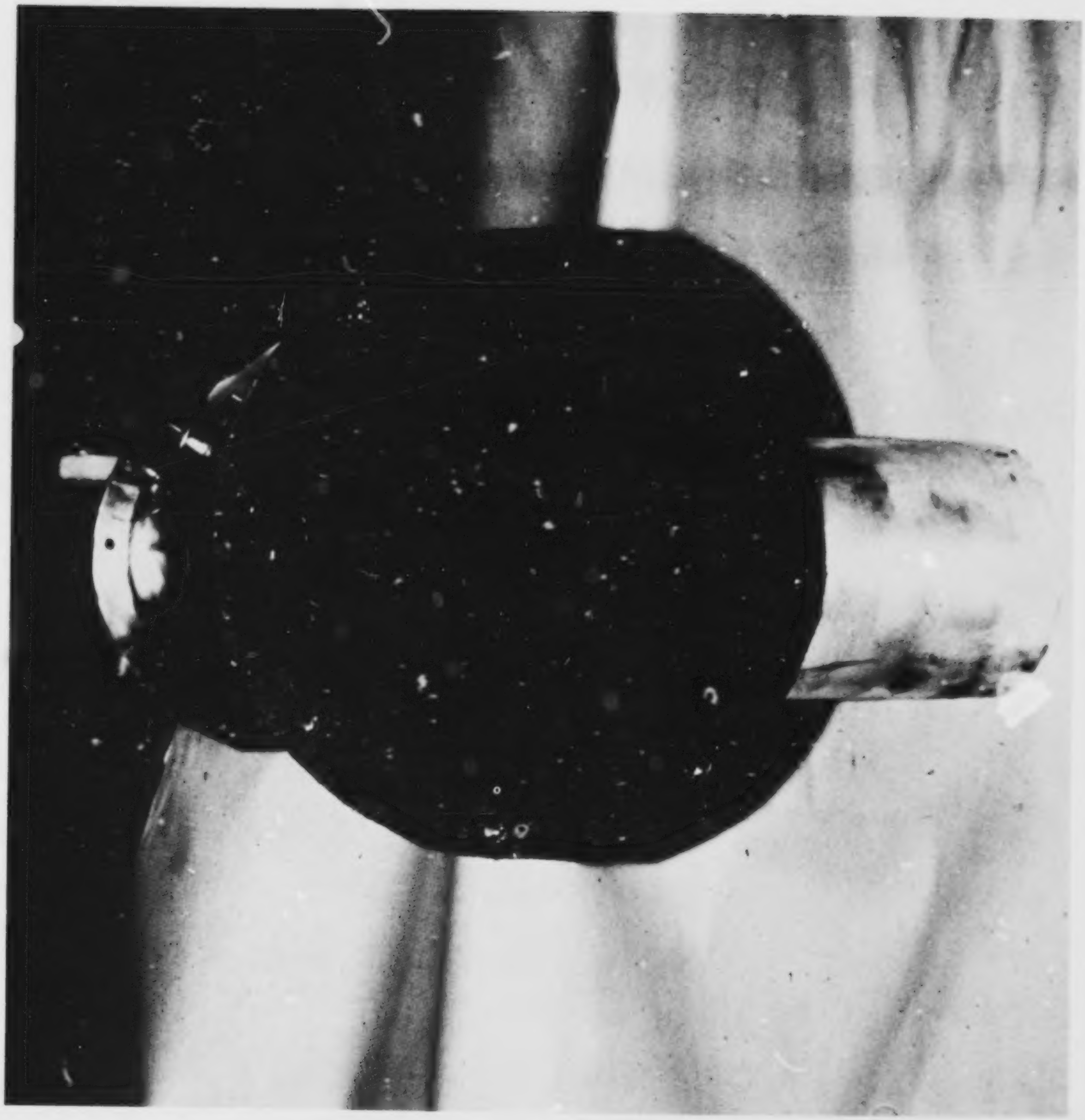
Next slide. #16

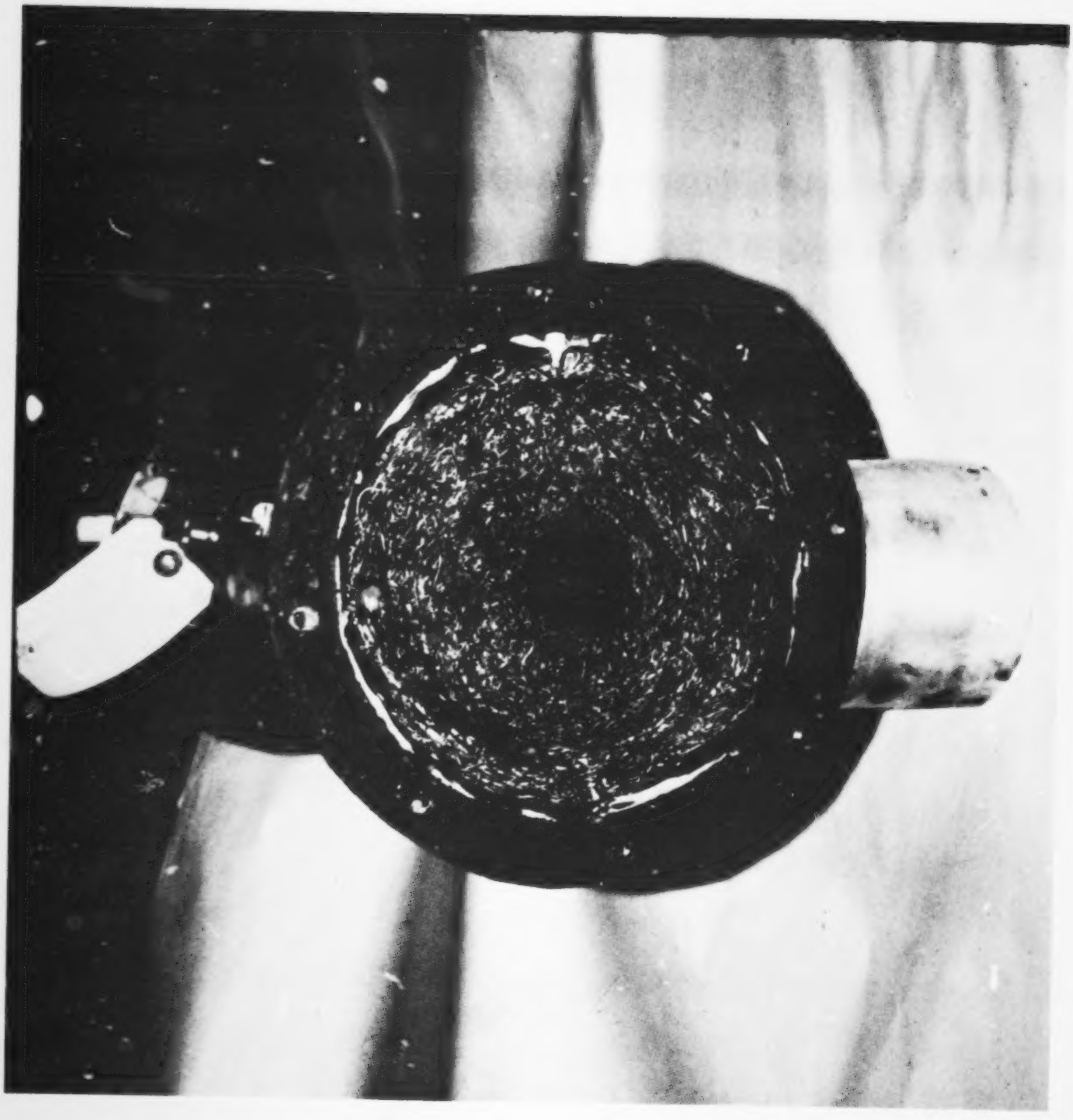
This is a view of the entry to that same unit after 1000 miles of operation in the laboratory during all these tests.

Next slide. #17

This slide will show the outlet of the large agglomerator. This is the outlet end, and you can see breakthrough occurring.







There are certain particles that are not being collected. We never had 100 percent collection.

Next slide. #18

Let us go now to the evaluation results and see what effects this final selected system had on the other emissions besides particulate. The system was installed under the car, and the vehicle operated with its normal factory exhaust system at the same back pressure that this trap system gave us. We are now running with one fan, with the hood up, just as we would if it were a standard EPA certification type test.

Next slide. #19

This shows the two exhaust systems side by side, to show you the relative difference in sizes. This is the little front unit that is normally on the car. We replaced it with the largest size we could still put under the car. This is the rear unit, and you have seen this one many times already. This is the separator device that was located at the rear bumper.

Next slide. #20

These are the net changes that we found when we compared the factory system to the trap system. In each case, these are net reductions in grams per kilometer of particulate by the various test procedures, the city cycle, the sulfate cycle, and the highway fuel cycle. You can see that the percent reductions are in the neighborhood of 33 to 40 percent. This is less than that 50 percent we had when we began; but the more we ran this system, the poorer the efficiency was.

I do not know what effect putting it under the car and changing the cooling regime had, also. That is not completely clear, but look at the tremendous changes in sulfate that we found. This is the first time that we had had an opportunity to measure for other emissions than just particulate. We are collecting on the order of 90 percent reduction in sulfate.

This car typically puts out two percent of the fuel sulfur in the form of sulfate.

EVALUATION RESULTS

System Under Car

Baseline at 7in Backpressure

SINGLE FAN, HOOD UP

PARTICULATE – SULFATE CHANGE

	particulate		sulfate	
	g/km	%	mg/km	%
FTP	0.1	33	7.0	83
SET	0.07	33	10.8	93
FET	0.08	42	9.0	93

Next slide. #21

Next is regulated emissions and economy, and without looking at all these numbers, there is essentially no effect from the trap system to the factory system in CO or NOx or fuel economy. The differences in hydrocarbons that we saw, sometimes one-third, sometimes a half, were very encouraging. The amount depended on the different cycle that we were running. This is extremely important. It was not completely expected, and it was very interesting to find this much effect. This is by the usual flame ionization technique.

Next slide. #22

This slide will go a little further into this. The hydrocarbons, as you know, are part of the odor problem. We did take a look at what the odor measurements gave us, and this was by the trained odor panel that we have used for many years.

Next slide. #23

This will show one of our panelists. This is the sniff cone. These are some of the bottles that are used for standards for which the panelist trains herself to relate the 100:1 dilution level that she sniffs at this point. This is well documented in the literature and I will not go into it.

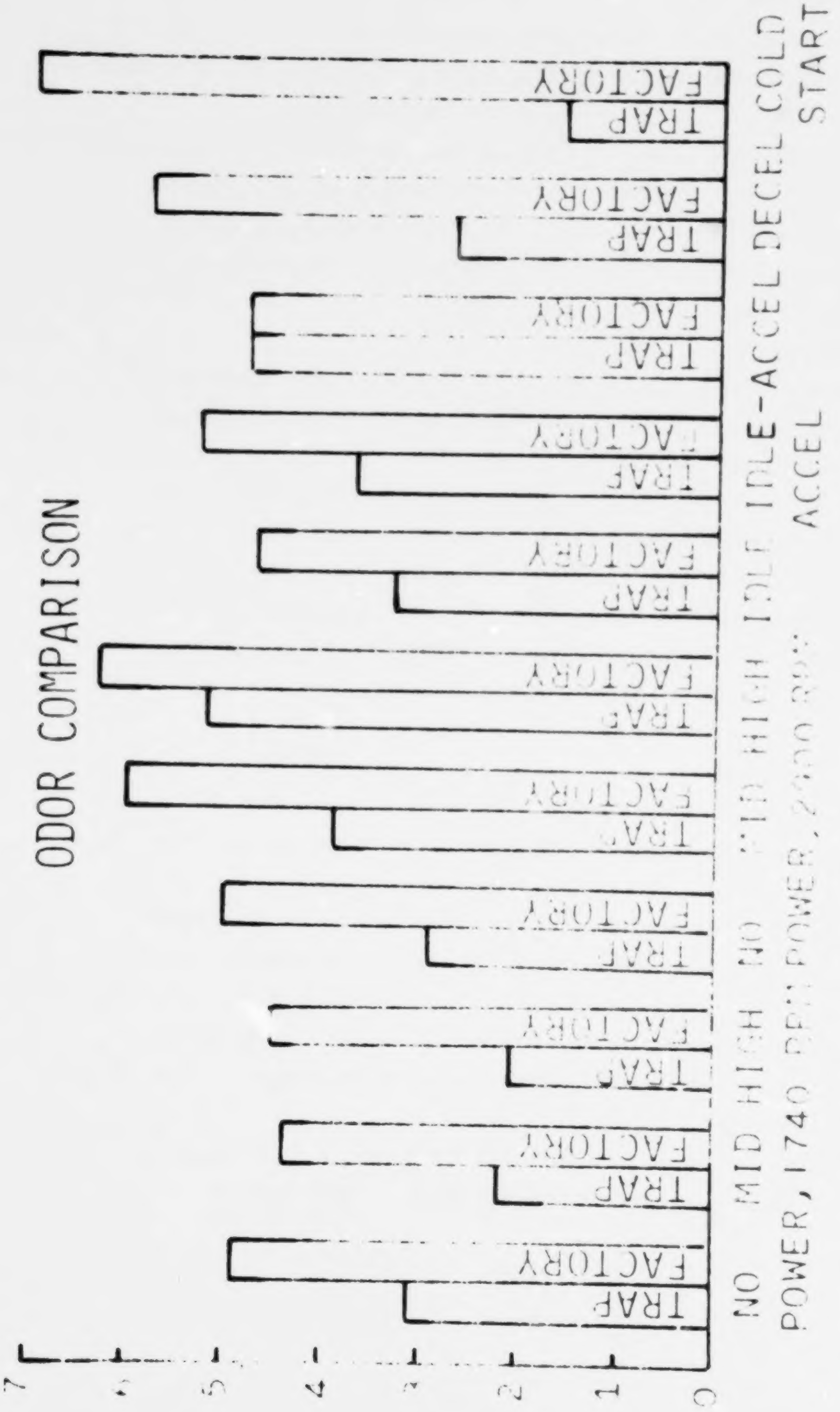
Next slide. #24

To summarize the odor work, we take all the results that the odor panelists give us, namely, the overall intensity and the four different qualities, and just add them up and see how the factory system stacked up against the trap system. For those who cannot see too well in the back, this is the trap system on the left of the two bars; and each of these pairs of bars represents a different type of operation. The first six conditions happen to be steady states, different speeds and loads. The next condition is an idle, just like a curb idle. Next is an idle acceleration and acceleration such as upshift in a gear, and then a decel and a cold start.

Look at the great difference in cold start effect here. That is the trap system, and that is without the trap system.

EMISSIONS – ECONOMY

		g/mile			Fuel
		HC	CO	NOX	mpg
FTP	Base	.31	.87	1.58	23.5
	Trap	.10	.77	1.49	25.4
SET	Base	.13	.63	1.37	29.4
	Trap	.06	.56	1.42	29.3
FET	Base	.11	.55	1.42	30.5
	Trap	.05	.50	1.42	30.4


ODOR COMPARISON
0
1
2
3
4
5
6
7
TRAP
FACTORY
NO MID HIGH NO MID HIGH IDLE IDLE-ACCEL DECEL COLD
POWER, 1740 RPM POWER, 2000 RPM ACCEL START

But look, there is essentially no effect here under the acceleration condition, as if the trap was trying to purge. Apparently, hydrocarbons collected under some other mode in the trap and then purged because of the violent amount of exhaust and heat this is coming through the trap during the acceleration.

All the other types of driving that we looked at, which pretty well suggest most driving patterns that people operate under, showed a substantial reduction. These are reductions greater than we normally see when we try other control devices purposely for the reduction of odor.

Next slide. #25

We also found that, somewhat to our surprise, substantial reductions in benzalphapyrene. These should be in micrograms; that should have been an Mu instead of an M. This is micrograms per kilometer. Again, the factory system is shown versus the collection system. Look at the improvements that we found, something between 30 and almost 80 percent over the different types of driving cycles. You can round that off to an average of about 60 percent. In any event, it was a consistent improvement in the BaP content of the filtered particulate exhaust.

Next slide. #26

We found some other effects. Of course, the noise was higher because of this very high velocity exhaust from the tangential anchored vortex separator; but that is a design problem. What really concerned us was the increased back pressure that was imposed on the engine due to the filtering. This system reduced acceleration performance drastically. It increased the time it took to go from, say, 0 to 40 miles an hour, or 0 to 60; overall, a 20 percent increase in time for accelerations was measured. Diesels do not need any more time for acceleration.

Next slide. #27

I want to speak just a little bit about a third topic that we looked into, and that was durability. I will explain it as

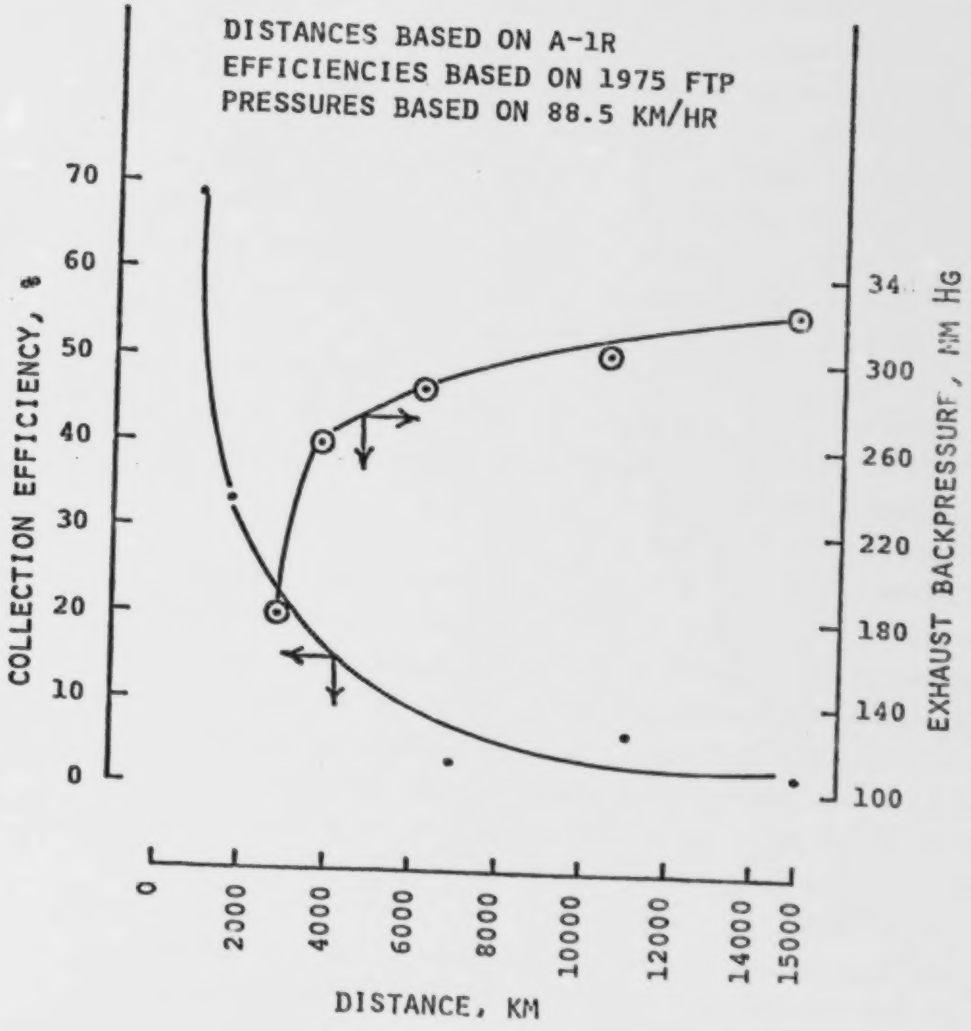
BaP EFFECT

	mg/km		%
	Base	Trap	Red.
FTP	7.2	4.8	33
SET	4.7	1.0	79
FET	3.5	1.5	58

OTHER EFFECT

Noise Increased directional due to TAV and location

Accel	Increased time due to BP
0-40	14%
0-60	20
20-60	21



DISTANCES BASED ON A-1R
EFFICIENCIES BASED ON 1975 FTP
PRESSURES BASED ON 88.5 KM/HR

FIG. 16 - SYSTEM EFFICIENCY AND EXHAUST RESTRICTIONS WITH OPERATION

best I can. The efficiency, that is, the trapping or collection efficiency, is plotted on the vertical axis. The distance traveled in kilometers is on the horizontal axis. This is MVMA mileage that was added on to the mileage that we put on the system while it was operating in the laboratory for all these extensive tests. We put a lot of miles on the car just in the laboratory.

You will notice how the efficiency has dropped off. When we first started, we were about 66 percent; and as the vehicle operated and the trap filled and collected more, the efficiency dropped off. At about 5000 kilometers, or about 3000 miles, we were down to about 10 percent efficiency; and we felt that, as far as we were concerned, it was a lost cause at that point.

We continued on to about 10,000 miles, or approximately 15,000 kilometers, just to see if we could ever plug up the system and to see what would happen. As you can see from our back pressure measurements, the more we ran, the higher the back pressure got; but it never plugged. We finally got tired and quit at this point, knowing that our efficiency was essentially zero at that time. The system filled, and that was that.

We wanted the aluminum filled cylinder to act as an agglomerator and then to purge periodically. We wanted to be able to collect this material in the separator, but it just did not do it the way we thought it would.

Next slide. #28

I would like to now do a quick summary of what has been covered. We were able to show particulate reductions of something greater than 50 percent with the alumina-coated steel wool. This is the Texaco system. They actually coated the material and furnished us the finished cannisters. The efficiency, however, was, to our feeling, essentially negligible after 3000 miles. It had a very limited life. We sort of expected it would have. It was either going to have limited life or plug up.

Next slide. #29

Recall, we had substantial reductions in odor. Odor has always been considered, at least by myself, as an indicator of

SUMMARY

Particulate Reductions >50%
with Al_2O_3 Coated
Steel Wool When New.

Efficiency Negligible After
3000 miles.

★ HC - 40% Less

★ CO, NO_x, Econ - No Change

★ BP - Increased 11 Times

★ Sulfate - 93% Less, new
59% Less, 9273 mi

★ BaP - Half Base

other things afoul with the engine; in other words, partially oxygenated materials, some sulfur compounds, nitrogenous compounds. There were substantial reductions in odor. Not only was there less odor intensity, but there was a different quality. It did not smell the same. I cannot say it smelled a lot better, but it surely did not smell any worse. It was an improvement, if anything. Several years ago, we used catalysts with buses, and the odor quality got worse because we just partially oxygenated some raw fuel. The exhaust odor would have been better if it had gone on through the catalyst.

The DOAS is the system that was put together by Arthur D. Little, IWe found its ratings to be consistent with the odor panel. I want to mention just a little bit about visible smoke. We found some accel peaks to be higher, such as a purge condition would be. With the trap filling and loading, there will be a certain amount of purge during a wide open throttle type accel. The increase in acceleration time to get to 60 miles an hour is of concern. This could interfere when entering an expressway.

Next slide. #30

Notice that the hydrocarbons were substantially less. There was no change in the other regulated emissions nor economy. The back pressure increased some 11 times by the time we got to the end of the test over that the normal system had. We were running a car that was partially stopped up.

The sulfate, as I mentioned, was not only less when it was new, but it was still showing less at about 10,000 miles. Of course, the BaP was half. I was asked to talk a little about some of the other after treatment devices and things that have been happening; but I know Dick Wheeler is up, and so is Dick Hurn, so I am going to leave that to them. I will stop at this time, and thank you very much for your attention.

MR. HURN: Thank you, Karl.

I think it was almost 10 years ago I had a very interesting conversation with some technical people from one of the major chemical

★ **ODOR** – Less I, different Q

★ **DOAS** – Consistent To Panel

★ **Smoke** – Lower, Some Accel
Peaks Higher

★ **Noise** – Higher at TAV Exit

★ **Accel** – Up To 20% Longer

companies in Britain. At that time, they described some very interesting work on soot deposition on materials, soot filtering, and, in effect, a technical approach where they considered that there was both catalytic activity in the system, as well as agglomeration and subsequent removal.

I believe that in one way or another, some of that work did result, in a way, or was connected with some follow-on work from Ricardo. I believe we are fortunate to see that work extended; and here, again is Dick Wheeler to talk about some of the work done at Ricardo on soot filtering. I know we will be interested to hear this.

MR. WHEELER: The subject is controlling diesel particulate emissions. Well, we have been doing quite a lot in Britain on this problem. I expect a lot of you are aware that one of the more important exports of Britain are diesel engines and the government departments concerned with this trade are a bit worried about what is going on over here, because what goes on over here spreads all around the world, and that is another a parameter in trying to sell diesel engines.

So, we need to know about this problem. The Department of Industry in Britain, which is the body concerned,with promoting exports and seeing that new technology feeds into exports. They have laid on a program to look after the particulate emissions from diesels from the point of view of failure modes, wear modes, bad setting up modes, stuck injectors, leaky valves, bad compression, worn rings, all the sorts of things that happen in practice, but manufacturers really do not know a great deal about; and EPA type tests rather nicely well set up, well selected engines; so this program is quite interesting.

It is fairly novel, and I do not think anybody else is doing this. It is being done by our usual technique of the particulate tunnel, in fact, the tunnel I described in the first session.

Figure 1 shows some simple results. I have not got full government approval to tell you all the results of the program since it is still in full swing.

The test unit is a direct injection engine of nearly 4 litres running up to 8600 revs. The effect of injection retard is shown. Five degrees retard does not do a great deal to the particulates at 1.5 Bar is shown, but 10 degrees gives a large increase. The opacity is shown in Bosch units, so Bosch tells you really nothing about that situation.

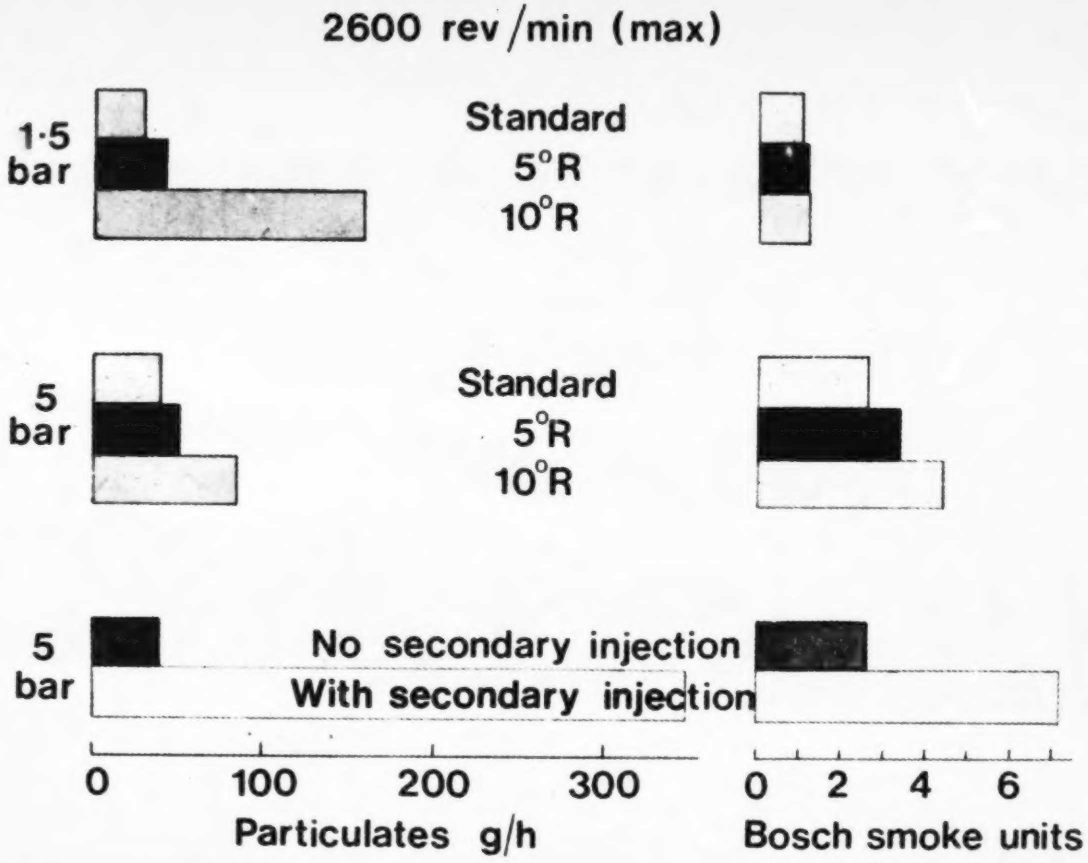
At 5 Bar, the amount of particulates given by an overdegree of retard is doubled; but here, again, the Bosch figures run reasonably in line and give reasonable check on the engine. We have induced secondary injections in this engine, and it made a dramatic change to the particulate levels and quite a reasonable change to the Bosch level, as well.

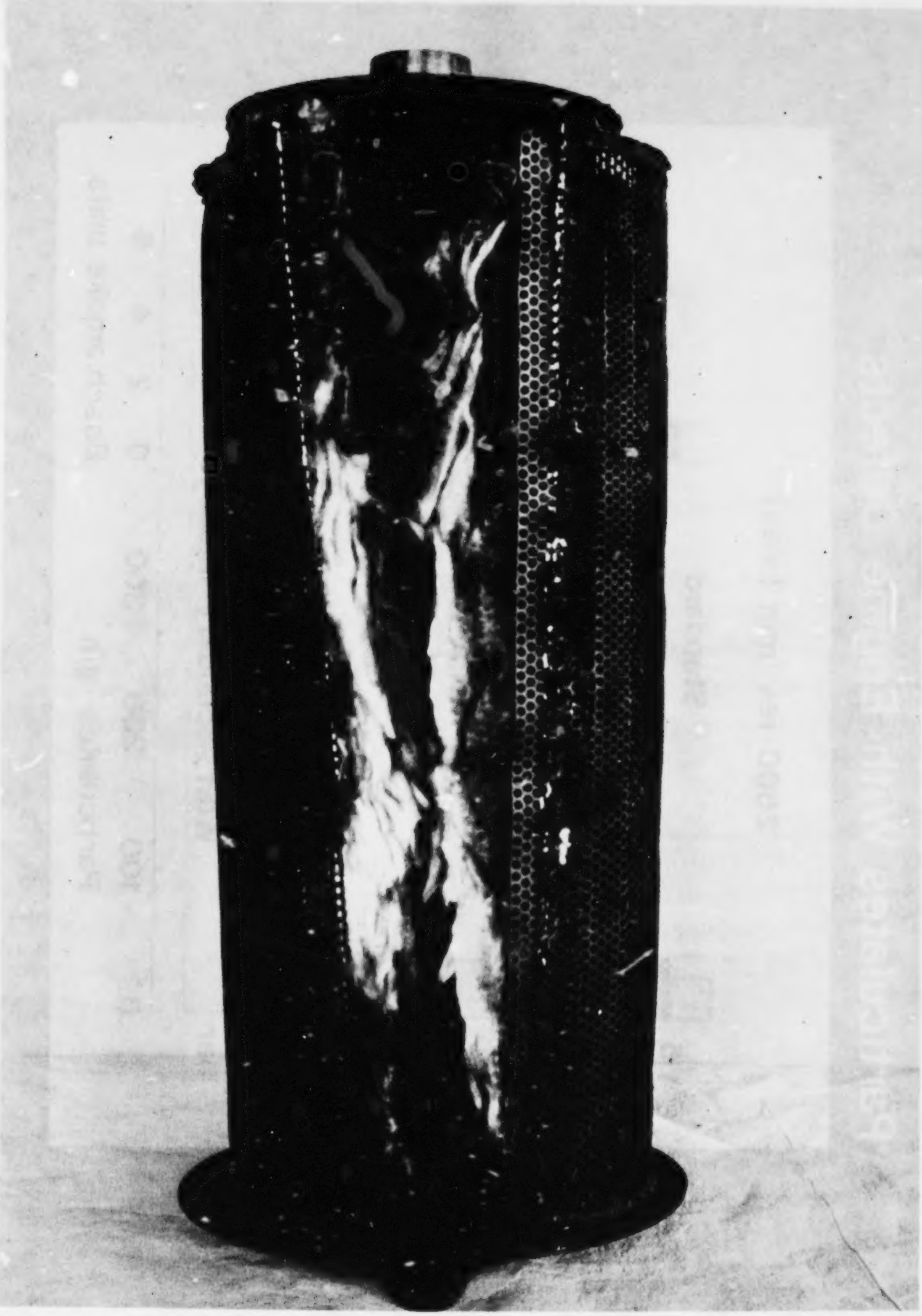
However, manufacturers do not, or should not, sell engines with secondary injections. Often some people who repair engines put the wrong pipes on them, and things like that do induce secondary injections. So, it is a possible problem with maintenance. I just mention this activity to show that the British Government is really quite interested in helping with this problem. It is laying on more work; and, hopefully, this will be published somewhere towards the early part of next year.

I think, in fact, that there could be some cooperation between my government and the American government in these areas. I think if it was laid on properly, it could be quite fruitful. I certainly would be pleased to give the name of the man in our Department of Industry who is concerned with this to anybody who thinks that this might be a good idea.

Well, to get on with what I have said, I would talk about, which is soot burning -- I mentioned this morning that we did some work some years ago for a major chemical company in Britain. They had a rather beautiful material, zirconia wool, shown on Figure 2. They asked us to test it for its ability to filter out the soot of a diesel

Particulates With Engine Defects





a diesel engine and, hopefully, to retain it for a given time in the hot exhaust to allow it to be oxidized away gently.

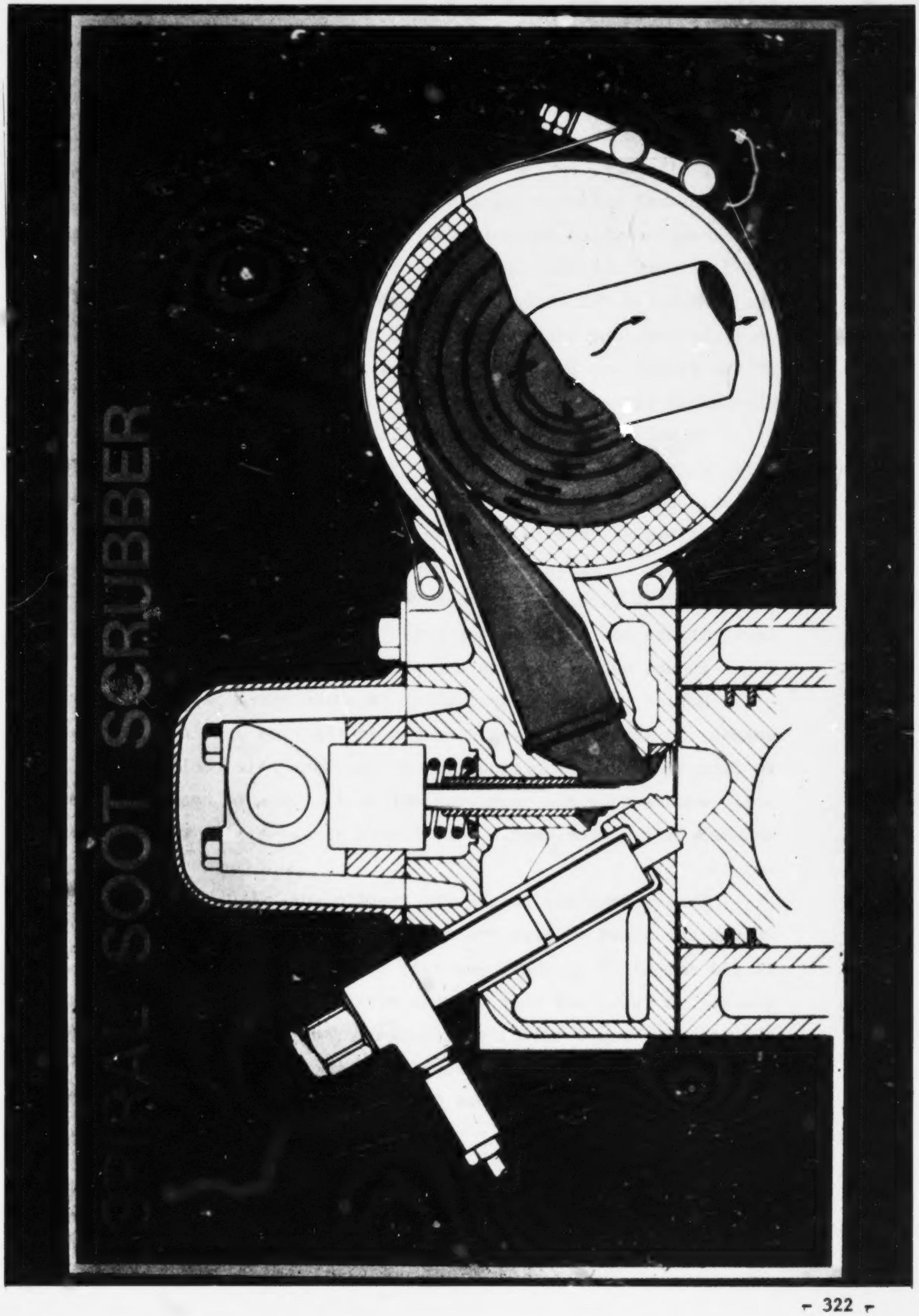
The sort of cannister that we used in those days is shown to be a very simple, straightforward through flow filter. The exhaust enters in the middle and blows out through the fibers. It had, like Karl Springer's device, quite a high back pressure. With a diesel engine running at full load, a direct injection diesel engine which has not that high an exhaust temperature, we could be very careful lagging and conservation of the heat, get the exhaust at full load up to about 680 degrees Centigrade; and we could burn the soot from a level of 4.5 Bosch down to 0.5 Bosch if the filter was pure zirconia, and about 0.3 Bosch if it was platinized zirconia.

It was only doing this at full load at high exhaust temperature, which with diesel engines, as Karl Springer says, is difficult to get. So, we went on from thereto the device shown in Figure 3.

It was an idea to overcome the high back pressure of the first device by allowing the exhaust to flow around a spiral, and on the spiral zirconia wool was trapped by a wire mesh. So, in fact, it was not a filter but a scrubber because the exhaust just flows in and out of it with the pressure pulses.

Notice the port liner, which is an integral part of the scheme, to avoid the water passages in the head cooling the exhaust. In fact, in a diesel engine, you do not want this cooling. We would much sooner the heat went out in the exhaust because it is a thermal load on the head. Port liners are a help to the engineer anyway.

That scheme was relatively inefficient. We only did about 20 percent clean up over the federal cycle.using a diesel car. It did not block as there was very little actual material there to block. In fact, all that happens with light load running is that the material would solidify with black soot, and then it would burn fairly quietly and noncatastrophically when the temperature got up to above about 425 degrees Centigrade.


SOOT SCRUBBER

We found that the burn would usually start at 425 degrees Centigrade and go quite vigorously. This, we believe, was due to the emission of sparks from the diesel engine. The mechanism probably resembles the way sparks transmit oxidation in the soot at the back of a coal fire. It is below what you would expect in terms of oxidation. Normally, rapid oxidation does not happen until over 500 degrees Centigrade. Anyway, we got quite good burns at 425 degrees Centigrade.

A practical version of the scrubber is shown in Figure 4. It is a very difficult, almost impossible, sheet metal worker's job to make; we have never really found a good way of making it. This has one modification from the spiral shown in Figure 3, which was a sheet of stainless steel, nonperforated. Here it is, two sheets of expanded stainless steel holding the zirconia in between. That gives a somewhat better performance because, in this case, the there is some scrubbing with the exhaust going around the spiral but, also, some through filtering by the exhaust being pushed through the matrix.

There is a tremendous optimizing job to do because one has to optimize the spiral gap to give a reasonable back pressure, which forces the exhaust through the matrix. In principle, if the filter blocks, all the exhaust must go around the spiral; but, in fact, after a burn off, much of the exhaust, over 50 percent, can travel straight out radially.

We next developed a simpler construction, Figure 5. We still used the expanded metal; and here, what we have done is to make a series of concentric rings which have a gap in them. The filter filling is no longer zirconia, because it is no longer available. Alumina, for most purposes, is just as good; but for this purpose, it, in fact, is not as the zirconia has a much greater resistance to thermal shock than the alumina. We constructed a box with a nest of these rings and optimized the gap width to the porosity of the material. This gives the correct amount of exhaust gas flowing through the gaps, and this then allows

you to optimize the back pressure against the amount of exhaust escaping through the gaps as well as escaping via the filter action.

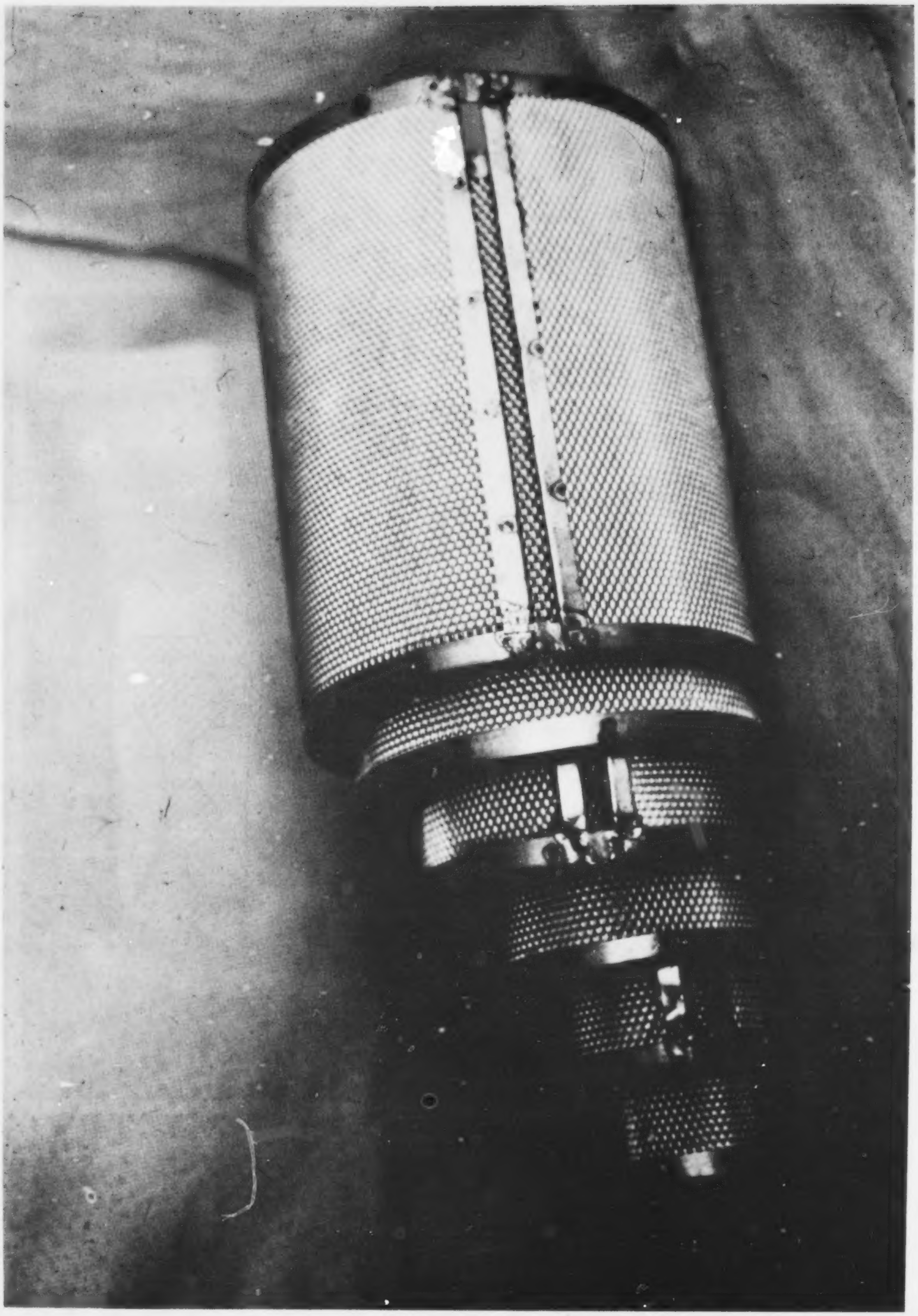
We have not optimized this filter yet, but it certainly works reasonably well. We are able to get,under load conditions, a steady 40 percent drop in soot level; and when the filter is taken apart, it never appears to be fully blocked. However, there is one severe problem when one tries to make too much filter action, then the soot that is collected on the light loads can occasionally, and unpredictably, light off and melt the whole matrix.

That is a problem we have not yet overcome. We cannot predict when it is going to happen. The amount of heat generated very quickly is quite extradordinary, and this is at temperatures which are certainly not at full load temperature. It can burn off catastrophically at temperatures around 500° C. We believe this must be due, to some extent, to the hydrocarbons adsorbed in the soot which probably develop most of the heat at this lower temperature.

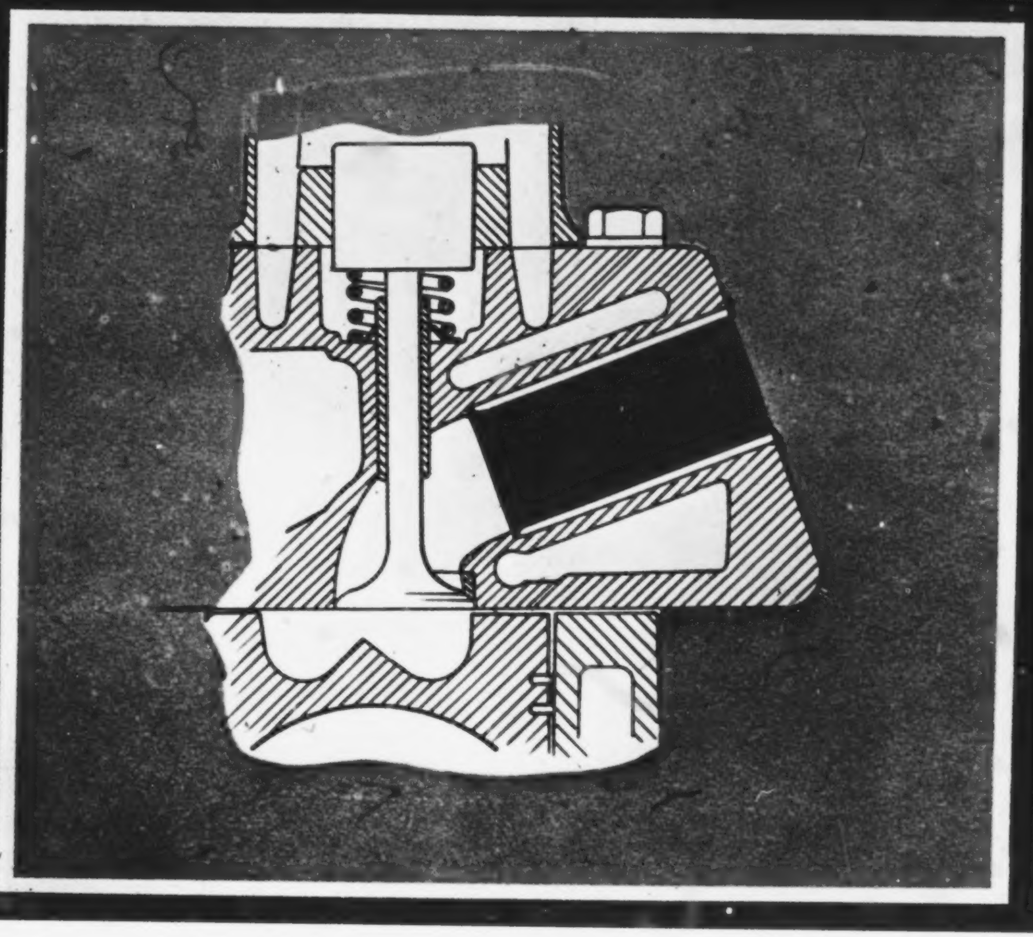
I think this problem can be got over, because if the amount of soot retention is limited on this filter,to below the point at which the matrix could be damaged. Again, we have not yet got to that point.

Figure 6 shows another view of the construction, and it is a very easy thing to make.

Well, the next thing we thought of was that maybe there would be a benefit in stopping the catastrophic burn off by getting rid of the hydrocarbons out of the exhaust before it reaches the soot filter. So, the idea now is to use a metallic fecraloy matrix as a port liner designed into the engine. (Figure 7) Unfortunately, no engine that we have exists with which we can do this easily. So, we have had to compromise and make this as an extension of the normal manifold; so, we are still suffering excessive thermal loss.



Fecraloy H.C. Oxidation Catalyst in Diesel Exhaust Port



RICARDO

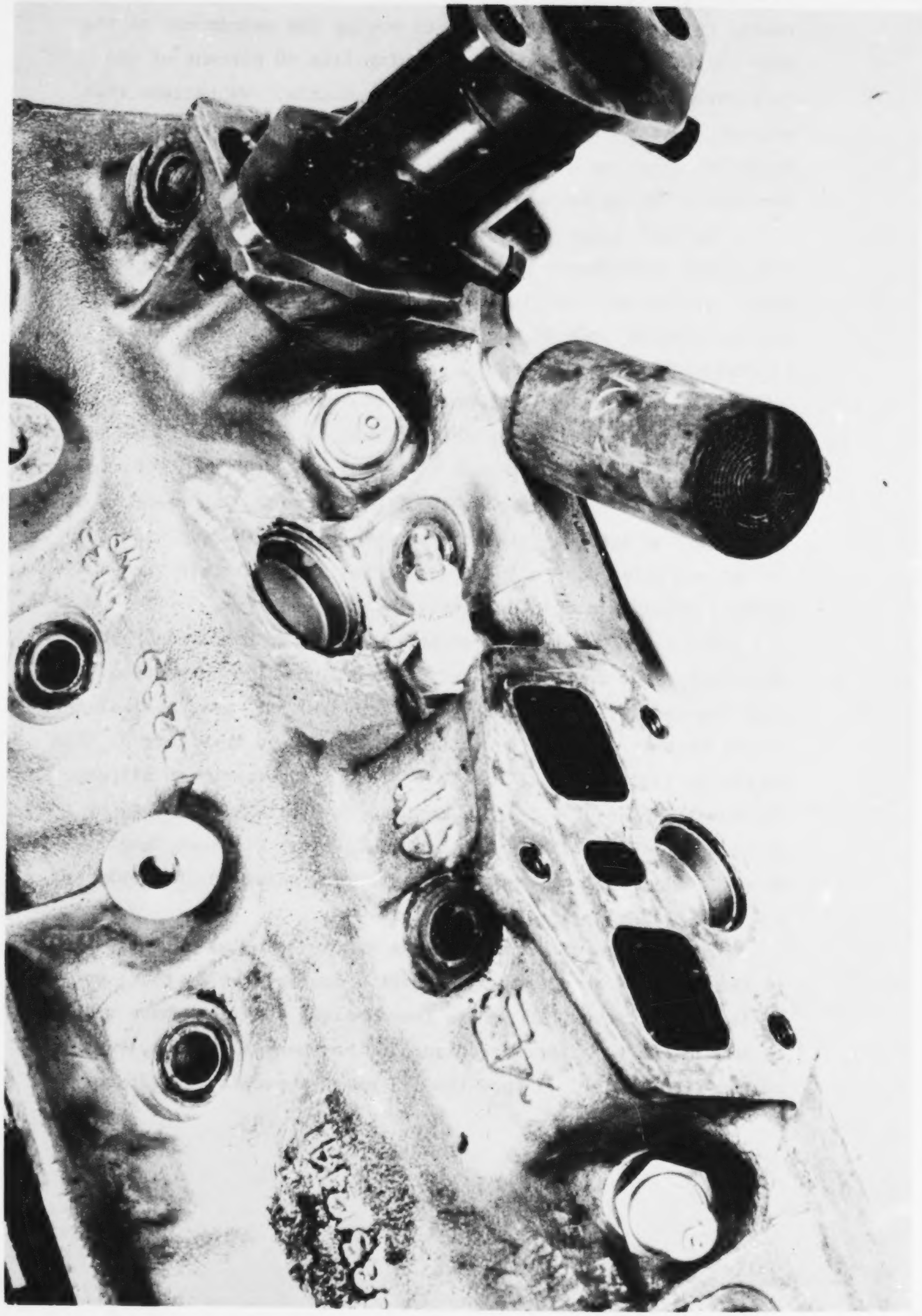
But we believe that a fecraloy matrix, platinized, would, in fact, get rid of practically all the hydrocarbons. We have tested this, but only the basis of moving the matrix out to the head face, and we can remove something like 60 percent of the hydrocarbons in a 2.5 inch long single matrix. We believe that most of the more complicated hydrocarbons are the ones that go first, although we cannot prove this. This is something that, obviously, has to be proved by biological tests.

The next stage is to combine this with the filter. We have done a few experiments on that approach. I would not like to quote results yet, but it looks promising. Certainly from such a system, particularly if the fiber material is platinized, the CO is virtually totally absent.

The hydrocarbons are, we believe, mostly methane, as the amount we get corresponds almost to what we would have expected as the methane content. The soot filtering is not really affected a great deal. It is still only about 40 percent. So, in terms of total particulates, at higher loads we would be having with this system something like a 50 percent total loss, in that the particulates would be almost certainly hydrocarbon free.

So, that is the point at which we are at the moment philosophically; but we have not yet made the actual construction. with the matrix in the ports. We have, however, used a similar system to that shown on a spark ignition engine in Figure 8. The matrix is isolated from this port steel extension by an air gap. The one shown is of 2.5 inch length. The ones we are using on the diesels are about 2 inches in diameter, about 2.5 inch lengths. We are really waiting now to get some work going on the design of a diesel head with integral catalyst.

This brings us, again, to the awkward problem of the sulfur in the fuel. I do not want to start a controversy on that; but it is possible that, if we are forced along the line where we have to have catalytic after treatment, we may need a premium, very low sulfur diesel fuel. I know the oil company people just do not



want to hear that message; and I do not think any of us do, really, because we do not know quite where that would lead us; but if we are talking about these systems, I think that is the obvious thing that would come along with it.

Something has already been said about barium antismoke additives. They are really not a tenable solution to this problem because work that we have done shows the actual mass particulate emission is higher with barium antismoke additives, certainly over an FTP, we got something like 30 percent higher, which you really would expect chemically. I hesitate to get into that controversy again;;but you would not expect one barium atom to react with something like a dozen carbon atoms, and it would need to do that to give you a net weight reduction, barium being 137 atomic weight, carbon 12.

But some researchers at London University were thinking about this problem and felt that there must be something in this, Why barium? Why is it that calcium is the next best and strontium is good, and lithium is good, and potassium? Why are these metals all good as antismoke additives? Why is it that when you photograph combustion with the antismoke additive present, that the smoke is never produced? It is not there, and we have shown this by combustion photography.

So, we argued that it must be an electrical effect because barium has the lowest work function for electronic emission, which is why it is used in the cathodes of electron tubes. Also, the metals I mentioned are all in about the right order of electronic emission which seems to be too much of a coincidence. To test this electron theory, they laid on an experiment, not with a diesel engine,because it was too difficult, but with a kerosene-burning jet combustion chamber. They injected electrons and charged species in to the combustion to see if, in fact, it was anything to do with just charged species. Immediately, it worked like magic, and it was so spectacular that we really did not believe it.

They used a very simple plasma gun, a machine in which you have something like 000 watts of electricity at low voltage, (20 volts and about 10 amps), and it is passed across a gap between tungsten and copper electrodes, and inert gas is passed through the arc giving a jet of plasma, as shown in Figure 9.

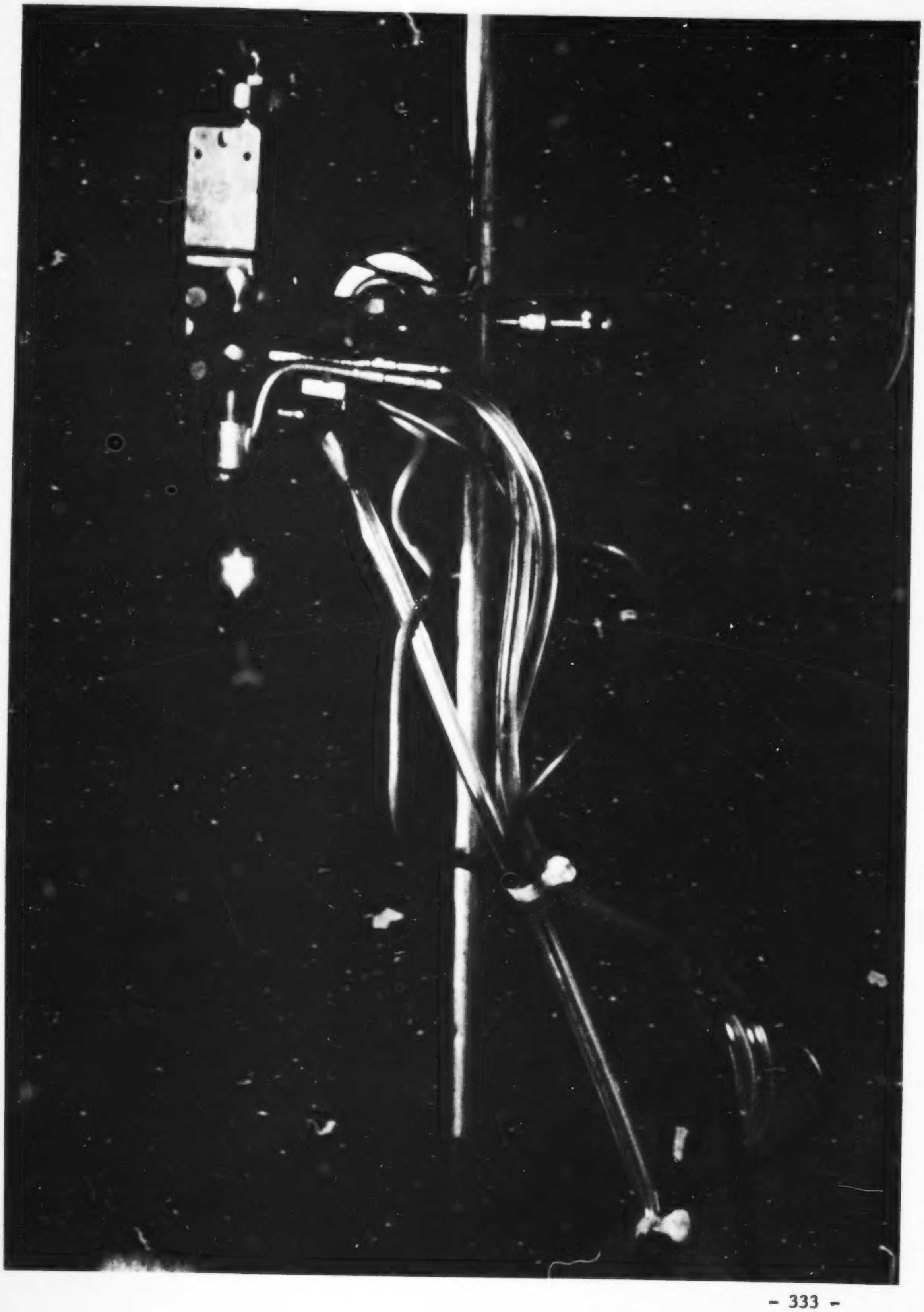
Nitrogen will give a pale blue plasma;argon gives a bright blue plasma. The best result is with argon, and the effect of this is shown later.

Figure 10 shows the baseline combustion looking into the back of the chamber, and the yellow, smoky flame is produced in a slightly air-starved turbine chamber. The swirl vanes are visible, silhouetted against the flame.

Figure 11 shows no change in conditions except that the plasma is switched on. Its glow appears at the top, and magically, the electric species of the plasma feed completely round the flame and the soot completely disappears. This is an argon plasma just because it is easy to make; but it happens just the same with nitrogen, with an air plasma, any plasma, as long as it has the right amount of energy.

The flame has something like 15 kilowatts of energy; and, with about 200 watts in the plasma gun, of which only a small percentage comes out as electrically charged particles, there is a 100 percent reduction of particulates; but with a system that we really do not know how to apply to a diesel engine. I mention this because the academic people may well care to contact Hilliard and Weinberg at Imperial College, London, who are doing it. I certainly think it is a good long term possibility.

One last soot removal possibility which, in fact, is already in use in mines is water scrubbing. So, I am surprised not to see Alec Lawson here from Ontario Research Foundation. He has been doing some very interesting work on water scrubbing following catalytic removal of hydrocarbons. This makes a spectacular improvement in water scrubbing because, presumably, it reduces the hydrophobic nature of the soot particle and allows the water scrubbing to become much more efficient.



If we are looking at systems for urban transport, such as buses, where they can be maintained on daily work schedules, maybe we should not turn our nose up at water scrubbers.

MR. HURN: Thank you, Dick. I know that others, as well as I, are very much interested to learn in greater detail what is being done and what is being looked at in Britain; and I am sure that we will be assessing that valuable resource further, Dick.

Quite easily identified as the major thrust in passenger car diesel development just currently in the U. S. is the GM development; and I am particularly pleased, then, to have the opportunity of hearing what is being done there and possibly what prospects they see for particulate control, and to tell us that, we have Dave Dimick. Dave?

(See (See GM presentation, Session A,ffor slides.)

MR. DIMICK: Thank you, Dick. Let me say first, I feel a little concerned coming at the end of this program because you are going to hear about a lot of things that you have already heard about today, in that the approaches are very similar on treating diesel particulates. You are going to have a chance, also, to see some of our General Motors tunnels, which I am sure you are going to be interested in; but we will give you a status report on where we stand at GM on the subject of particulates.

We have been increasingly concerned with the problem of particulate emissions for several years, and we have had programs at both our research staff and our engineering staff and in our car and component divisions in an attempt to reduce particulate emissions.

Diesel engines, as you have already heard, offer us an improvement in fuel economy of approximately 25 percent. In order to reduce energy consumption, as I am sure you are aware, GM is planning to use increasing numbers of diesel engines in our products in the future.

We are particularly concerned about particulates because they could be a roadblock, really, to widespread application which we would hope for in the future.

Today, I intend to outline our reasons for concern, show you some typical emission levels measured at our facilities and describe the efforts of the General Motors engineering staff to reduce particulate emissions.

Next slide, please.

We consider diesel particulates important for the reasons shown here. A diesel car, as you have already heard, emits about 10 to 30 times the particulate mass of the modern car running on unleaded fuel with the catalytic converter. In some circumstances, these particulates can be aestheticaly objectionable.

They are respirable, and though we have seen no evidence to date, we are concerned that they could be a health problem. They contaminate the engine oil; and if the oil is not changed regularly, they could contribute to engine wear. Last, of course, government regulation is imminent; and if the standards are set too low, this could preclude future production of what we think of as a very fuel efficient engine.

We are particularly concerned that the levels established may preclude the use of diesels in large cars, where they really represent the greatest energy savings.

Next slide, please.

Just a brief description of particulates is in order, and I know you have heard a lot about this this morning. They result from the inhomogenous diffusion limited combustion process which is inherent in diesels. They are small, in the submicron range, and they are coated with condensed oils, and they are found to have a very low bulk density. We routinely measure vehicle particulate emissions using a modified CVS tunnel, as shown here. We intend to submit some data for those of you that are concerned about a major modification in tunnel requirements, we will be giving a lot of data to Merrill Korth to support our use of this type 66 tunnel.

We measure the particulates on the federal test procedure, using the city driving schedule.

Next slide, please.

This chart shows typical particulate emission rates. The measured average rates range from about .3 grams per mile for the smallest car to about .9 grams per mile for the largest. The .3 grams per mile, as you have already heard, is the range of our cars when they use leaded fuel; and, as you have also heard, we are down about 1/10 of that at .03 grams at the present time.

Next slide, please.

Our program at GM started several years ago. Its objective has been to reduce particulate emissions without losing any advantages of the diesel. Tasks, as I have listed them here, are very similar to the ones that you have already heard. There are only three basic approaches to the problem, modify the engine, modify the fuel or clean them up in the exhaust, and we would hope for one of the first two being the right solution.

Next slide, please

First problem we have got is measuring emission rates and particulate properties so that we understand what our progress is. We use constant volume sampler tunnels for mass measurement, electric aerosol analyzers for size measurement, several types of smoke meters, and we also do a number of different types of compositional analyses, again, much like you have heard about already today, and I will not go into those.

This is our constant volume tunnel, which I am sure you are all glad to see, having seen about five of them already.

Go on to the next slide.

There is the way we have modified the CVS tunnel actually in a chassis dynamometer. It is a minimum modification; it does not require a major facility change, and it is the kind of facility that we would hope would be used for measurements.

Next slide, please

This shows the type of dynamometer type tunnel that we are using in our engine cells.

Next slide, please

The second work area that we have had is to modify the combustion process to reduce particulates. The work on Task 2 involves single cylinder tests of modified production engines. We have used the General Motors 2.1 liter Opel for most of our work to date. We also use a special fuel injection bench together with special injectors and fuel control.

These allow variations of just about all of the injection parameters. The general objectives of this task are to effect the particulate production by improving either the air/fuel mixing process or by controlling combustion rates or by optimizing the chamber wall temperature.

Next slide.

This is just a shot of our 2.1 liter Opel engine in a dynamometer cell. We have run a large number of tests on this type of engine with over a 100 configurations directed at particulate reduction.

Next slide, please.

We have evaluated a great number of combustion chamber designs, and we have tested with the flexibility afforded by our fuel bench, a great many injector designs, orientations and injection parameters. I am sorry to say that, to date, we really have found no success in lowering the particulates significantly, except at very isolated operating conditions.

We have found a number of ways to increase particulate emissions. This is not really too surprising, in fact, because, although we are measuring particulates, almost all of the passenger car diesel engines have really been developed with the idea of low smoke. So, it did not come as a complete surprise to us that we were not going to make any major changes. I will touch just on a few test results as examples for you.

Next slide, please.

This shows an example of one of our investigations into modified combustion chambers in the Opel engine. This particular example, we were investigating reduced swirl in the pre-chamber and the potential of plated catalysts in the combustion chamber.

Production Opel engine is shown with the heaviest line on that chart, and you can see at the bottom that this is one of those examples where we were unsuccessful, raising both smoke and particulate levels of the engine.

Next slide, please

This is the second example of some of our test data. In this case, we were investigating alternative injector locations, spray directions, and injection pressure. In this case also, we were able to show only small improvements in particulates and, then, at the expense of some other parameters.

Next slide, please.

We are continuing with this work with the Oldsmobile engine, because we really believe that the control of particulates in the combustion chamber is the ideal solution; but, as you have seen, we are finding this very difficult to accomplish.

Next slide, please.

Our third task involves evaluating various fuel modifications. We are working with both fuel and additive companies, and they have contributed greatly in this effort. There are at least four basic ways that fuel modification might reduce particulates. If particular hydrocarbon classes are primarily causes, their removal within refinery limitations might help.

Additives might inhibit the reforming or catalyze the carbon combustion. Some effects might be primarily mechanical; that is, serving to improve the mixing and atomization process. Several approaches are being evaluated in attempts to obtain these effects. These include alternate fuel blends, additives, emulsions, and preheating of the fuel.

Next slide, please.

We are also doing some very detailed studies of particulate sources. We are doing this by radioactively tagging constituents of the fuel and the oil. This cell that you see here, we are evaluating the radioactively tagged fuel. In this way, we hope to identify the specific cause of the particulate formation.

Next slide, please.

An example of the effect of fuel is shown by comparing particulate emissions with No. 2 diesel fuel and kerosene. The fuel change increased smoke and oxides of nitrogen emissions; however, particulate emissions were much lower on kerosene fuel. The differences are believed due to the combined effects of increased volatility and lower aromatics.

Next slide, please.

We have evaluated a great number of fuel additives which have been suggested and provided by our fuels and lubricants research personnel, additive companies and oil company research and development personnel. Some have shown decreases in particulates, which I am showing you here. There are others that have had no effect, and there are some that have given amazingly large effects, often accompanied by smoke reduction.

This plot shows only those that have given some indication of particulate improvement in our preliminary screening tests. In this dynamometer test, they have demonstrated from 10 percent to 50 percent reductions at single engine operating points. The best of these have then been car tested, where improvements of from 5 to 15 percent have resulted.

Next slide, please.

We have also evaluated water and oil emulsions. Water and oil emulsions may improve mixing by micro explosions of the water. Also, they help in carbon combustion by supplying hydroxyl radicals to the rich combustion zone. Tests of the emulsions have given very mixed results that varied significantly with operating conditions and injection timing.

The broad area shown in this plot encompass the many test points using various amounts of water and surfactent. This data is from an Opel engine at 40 miles per hour road load, and you can see that there has been some particulate reduction.

Next slide, please.

This is just a brief summary of the results of our fuel studies. None of the improvements at this time appear sufficient to warrant general use except the alternate blends. We are advised by some of the oil companies that these are very doubtful availability for widespread automotive application.

Further, we have some concern in that we are not finding the same levels of improvement as we begin applying some of these Opel engine data to our Oldsmobile engine, shown in the right column.

Next slide, please.

Our fourth task is to develop practical methods of removing particulates from the exhaust gas. This is not the most desirable method, as it does not alleviate the engine oil contamination problem and requires add-on hardware with resultant weight size and cost penalties. Nonetheless, it has received increasing emphasis, as the difficulty of solving the problem in the combustion process by modifying either the engine or the fuel becomes apparent.

A number of approaches to exhaust cleanup have been considered. The particles are much too small to be removed by centrifuges, and you have seen some report to that effect by Karl Springer. The water scrubbers do not appear practical to us for passenger cars, although they might be applicable to some commercial vehicles which could be serviced on a short periodic basis.

We have done some work on electrostatic concentration of particles. Our results were relatively poor and inconsistent, and we felt when we concluded that, that really the approach would not be practical for motor vehicles. We have also worked with oil bath filters, which are moderately effective in removing particulates, but, unfortunately, add tremendously to the hydrocarbon emissions.

We have even considered such exotic concepts as molten salt baths, but we do not feel that that type of thing is practical. At this time, it seems to us that passive trapping, as you have heard already, is probably the only practical approach; and our effort is concentrated in this area.

Disposable traps appear to have limited potential at current emission levels. Because of the low bulk density of the particulate, a relatively clean car, say, .3 grams per mile, emits about a gallon of particulates in about 1000 miles. So, volumetrically, this does not appear to be practical.

However, it is the simplest solution; and it could become practical in the future if we could make some progress in the combustion or fuel area. At present, it appears necessary to trap and store temporarily until trap loadup requires regeneration of the trap.

I will take just a few moments to discuss our trapping activity. Because of the very small size of the particulates, about a tenth of a micron, we think the primary trapping mechanisms are diffusion and electrostatic attachment. For these to be effective, the trap material must have a very high ratio of surface to volume. The required properties of a trapping material are high efficiency, high capacity, and low pressure drop.

Next slide, please.

A substantial number of material types and variations have been evaluated as listed here. Most were deficient in some way. A few show good properties and are being developed. In general, fine, fibrous materials have high trapping efficiency, but block too quickly. Particle collects only at the entrance phase.

One promising material class, which Karl Springer related his experience with, is the porous alumina-type steel wool with an alumina coating.

Next slide, please.

This chart is an electronmicrograph of one such material, showing the highly porous coating, as well as the very large pores. This material achieves efficiency of the order of 50 percent, and good, relatively slow, back pressure buildup.

Next slide, please.

This looks, again, something like Karl showed you. It is the front face of a new trap of this material.

Next slide. This is after it is loaded up.

Next slide. We have built a number of different traps of this material for under floor installation, as shown here.

Next slide. We have installed them and tested them on both Oldsmobile and Opel vehicles. Here, two are shown installed on an Oldsmobile.

Next slide. This shows a typical trap configuration for our Opel Rekord vehicle. The trap replaces the muffler or the resonator or both, if desired. Good trap materials have good muffling properties, so we also have no noise problem with the car.

Next slide, please. We have also evaluated traps on the Opel which would replace the exhaust manifold.

Next slide, please This chart shows typical trap performance on an Opel Rekord vehicle. The three columns show performance with a muffler trap only, with both a muffler and a resonator trap, and finally with these plus manganese doped fuel. Nominally 50 percent particulate reduction was achieved with a single trap on the urban test cycle.

With both traps and a special fuel, a two-thirds reduction was achieved; and it should be noted, as you have seen earlier, that about 30 percent hydrocarbon reduction was also achieved. The noise, as shown at the bottom, was relatively unaffected. However, after about 700 miles, the trap was loaded and the back pressure was rising rapidly.

This is obviously an impractically short service interval, and we will have to find some satisfactory method of trap regeneration. By removing the trap from the vehicle, trap regeneration could be accomplished by incineration or other methods.

However, we believe this is an impractical requirement for a passenger car, or even most commercial vehicles, at such a short interval. For this reason, a considerable effort is now being applied to conceive and develop practical methods for in situ type regeneration.

I would like to mention as a final note that the diesel particulates problem is closely related to the NOx control problem. You have seen data to this effect earlier. The most effective way that we have found to control NOx is with EGR; and, unfortunately, we find that the use of EGR does increase our particulate emission rates. This is a subject in its own right, and there is not enough time to cover that at that time.

Next slide, please. As a final summary of our progress, we have active particulate reduction activities ongoing in both our divisions and staffs at GM. We now realize that it is going to be difficult to lower particulate emissions much below the levels obtained in current, highly developed engines, except by trapping.

Further, it is apparent that the development of a practical and reliable trap system is going to require a major engineering effort, and there is no assurance of success at this point in time.

Thank you.

MR. HURN: Thank you, Dave, for a very excellent summary review of what GM is doing in that area. We have one last presentation I would like to cover before we give the group a chance to answer some questions that you might have, give you a chance to hear their answers.

Some of you who have just recently come into the diesel picture in your experimental technical work, will be surprised, I think, to know that work with diesel emissions, diesel particulates, has been underway for quite a number of years, particularly in the mining industry and other places where diesel smoke was objectionable in confined areas.

The Bureau of Mines,has been active in this work for a number of years. John Murphy, with the Pittsburgh group of the Bureau of Mines, has been associated with that work for some time. John will review for us their experience in the diesel program, give us some indication of what they are doing now, and I believe associated wit with that may be a few remarks from Bill Marshall, who is associated with me at the Bartlesville center.

John?

(Written paper follows oral presentation. Slides not included in oral presentation.)

MR. MURPHY: Thank you, Dick. It is a pleasure to be with you, and I will not show you any dilution tunnels. But let us go right to the slides and have an opportunity to give you a little bit of insight into the Bureau's program on diesel-related research.

Next slide. You get a little bit of background about the various aspects of the problems and the types of things that we are trying to address. Basically, if you look at these interlocking circles with the ultimate goal of safe utilization of diesels, that you have the approval requirements across one side of this triangle, you have the types of parameters that affect emissions both from the initial engine and its approval by what used by be called MESA, now it is MSHAW (?) as of a month ago, and the options that are available to the operator in terms of how he maintains these emissions in the field as a function of wear, either in terms of maintenance of the device or increased ventilation.

Next slide. You look at the basic elements of our program as we address these objectives, the emissions control, characterization, field studies, instrumentation and monitoring, and not a direct interest today, but an important one, is noise.

Next slide. Under the emissions control, we have had a variety of activities underway. As you see here, catalytic work, some scrubbers, looking at alternate fuels, looking at some of newer engines and how these may impact the underground situation and, also, look at it in terms of external combustion for some of the activities.

Just to look very briefly, in the interest of time, the catalytic work has principally been directed toward both particulate and gaseous emissions control, and there is a lot of data available on this. If someone is interested, we would be happy to make it available. The work of scrubbers -- I will show you one just a bit later -- but in addition to some of the Texaco-type work that you have heard about, we have been looking at some water scrubbers.

While our problem is more severe underground in terms of the environment, I think we have some liberties to look at some features that you cannot consider on a routine basis for passenger or light vehicle fleets. One of these is scrubbers and the use of water scrubbers, as has been addressed. Another is in terms of alternate fuels.

I was interested in the comments about the kerosenes, because we have looked at some of these; and even in terms of deodorized kerosenes, we get even more markedly interesting reductions in emissions and, again, let me make the point that the increased cost of a special fuel for the mining industry may not be out of the question in terms of our particular application.

Yes, there will be significant distribution costs for this particular type of use, but I think it is certainly worthy of consideration. In the area of new engines, we have looked at some of the newer engines, and it is quite encouraging in terms of the new designs of the sizes used in underground mining what the overall emissions picture is as compared to the ones that are used on a routine basis.

Last, but not least, is external combustion in terms of like the steam engines or sterling engines; again, have some promise and some of these are coming along to the point that there are preproduction prototypes that, if they are suitable, have application.

Next slide. I mentioned the water scrubber. This is one that was initially designed for respirable dust control by the Bureau. It is a flooded media, and for respirable dust, we get about 95 to 98 percent particulate removal. For diesel particulate, which is smaller by about an order of magnitude, preliminary results are in the 50 percent range.

Perhaps by some agglomeration techniques, like have been discussed awhile ago, we may be able to improve efficiency.

Next slide. Okay, just to walk you through this triangle, again, now -- basically speaking, when a new engine is approved for underground, there is a specific set of ventilation requirements established; and then a mine operator, if he elects to use this particular engine, and I should say engine plus emissions control system, he has a fixed set of parameters to work with in terms of ventilation and maintenance.

Next slide. Now, any emissions characterization, both from new engines and those in the field --

Next slide. We have been involved in these particular areas, analytical procedures, laboratory evaluation, the first two principally through the Battlesville Energy Research Center, and through a variety of field studies, most of which have been conducted by Dr. Johnson, whom you heard from before. I will not elaborate on these in the interest of time.

Next slide. The engine emissions measurements in the field, as in the laboratory, are important considerations.

Next slide. We see numbers like this just in terms of performance of systems with catalysts. This is laboratory data, but we are presently going to look at how these deteriorate in the field as a function of various types of maintenance and/or lack of it.

Next slide. The field maintenance procedures, we feel, are very critical in terms of the overall mining environment. It is one thing when a new engine comes in and it has a particular approval requirement, and one decides what the ventilation is and to maintain this particular level in the field, of course, requires either maintenance, as I mentioned, or increased ventilation.

Next slide. So, here we have the lower side of this triangle and this particular aspect of the underground problem.

Next slide, In the field studies we have been involved in a variety of things that basically can be categorized as follows.

Sampling procedures, instrument evaluation, ventilation, and methodology. The work has gone into both coal and non-coal mines, looking at where you sample and how you sample, making determinations as to whether one has to sample for all the particular species that are involved underground, or could you use particular tracers that are available from the exhaust emissions.

As an example, it appears as though carbon monoxide may be a good indicator of what the overall mine environment is; so the mine inspector or company personnel could use this, using a CO_2 instrument, to get a firsthand initial indication as to what the general mine air quality is. I will say a few more words about instrumentation later, but through these fuel studies, we have had an opportunity to assess the reliability of things in the field.

We have heard a lot of discussion about instrumentation in the laboratory and, obviously, this is needed and you have greater control. But the underground problems for simple measurements in many cases are rather severe.

In ventilation, in addition to the in-mine studies, we have done a lot of ventilation modeling in terms of being able to predict how the levels would be from a particular configuration. Of course, methodology ties all these together in terms of how you assess underground operations.

Next slide. Just very briefly, this is some of the underground work. This is Dr. Johnson's laboratory that he has had in a variety of mines and, through this type of mobile but mineworthy instrumentation, been able to make assessments of various conditions to get statistically significant indications of how these parameters vary with various operating conditions.

Next slide. Not only do we do laboratory work, but also with portable instrumentation up in the face areas, to make determinations.

Next slide. Ventilation is obviously important. It is also an expensive control parameter when you really look at the cost of this; and so, one has this as an option, as I pointed out earlier, that it is not the preferred way to minimize exposure levels.

Next slide. We have spoken about air quality measurements. This is what ties this side of the triangle together, if you please, in terms of determining that the underground working environment is safe.

Next slide. This just that particular aspect up. The air quality measurements are receiving increased significance in terms of how one does this. There is quite a bit of interest in stationary mine monitoring systems; and as these are set with the approval of an engine, these are critically important in terms of an underground day-to-day operation.

Next slide. In the instrumentation and monitoring area, ther there are a variety of things, and I am just going to go through these very quickly.

Next slide. Believe it or not, the state-of-the-art in underground instrumentation for foutine measurements is length of stain tubes; and while these have been used for quite a few years, they have limitations, as indicated by this slide, with an overall accuracy of plus or minus 25 percent, a significant portion of which is due to the observer under mine lighting conditions.

Next slide. There are a variety of new technologies that are available and now being used, either on a commercial or preproduction prototype basis, like electrochemical CO, NO, NO_2 d devices, that we feel have a lot of promise for the in-mine monitoring application. I just included this, we talked about all the problems of instrumentation, we have some very severe human factors problems in terms of underground mine monitoring.

Next slide. Another area is dosimetry, and there have been developed through Bureau funding recently some dosimeters, particularly for NO and NO_2, and it is basically this little device on the back of -- it can be worn on the hat or any place else that is particularly appropriate.

Next slide. Another area that has considerable promise in terms of insuring safe working conditions is vehicle mounted monitors and this is one of the two types of carbon dioxide monitors that have been evaluated extensively underground, and we expect can be used to address the problem of insuring adequate air quality for the operator. This is the reat(?) device you see here in the operator's station.

Next slide. This is the device itself mounted on the vehicle.

Next slide. I mentioned environmental monitoring, stationary monitoring, before. This is just one of several devices that are available. This particular one measures carbon monoxide air flow and methane, if you have a need for that particular application.

Next slide. In the area of noise, just briefly, we have been involved in identification of sources and control procedures for diesels, and here you see an LHD which typically runs on the order of 100 to 101 DBA; and, through some control procedures, we have been able to get this down to about 92 DBA, which gives you full shift compliance for the underground operator.

Next slide. This is just another example. This is a dispatch vehicle, diesel-powered; and through some rather simple noise treatments in this particular vehicle, we got it down below 90 DBA, which is helpful in terms of letting the miners receive higher exposure during other parts of the shift.

Next slide. So, in summary, this is a very brief overview of engineering applications work that is involved, and I would like to take this time to thank you for your attention and introduce Bill Marshall, who will describe in a little more detail a few of the things that I have mentioned and some others. Thank you very much.

BUREAU OF MINES DIESEL RESEARCH

Presented by
John N. Murphy, Research Supervisor
Pittsburgh Mining and Safety Research Center
Bureau of Mines, U.S. Department of the Interior

Workshop on Unregulated Diesel Emissions
and Their Potential Health Effects

Department of Transportation Headquarters
Washington, D.C.
April 27 and 28, 1978

ABSTRACT

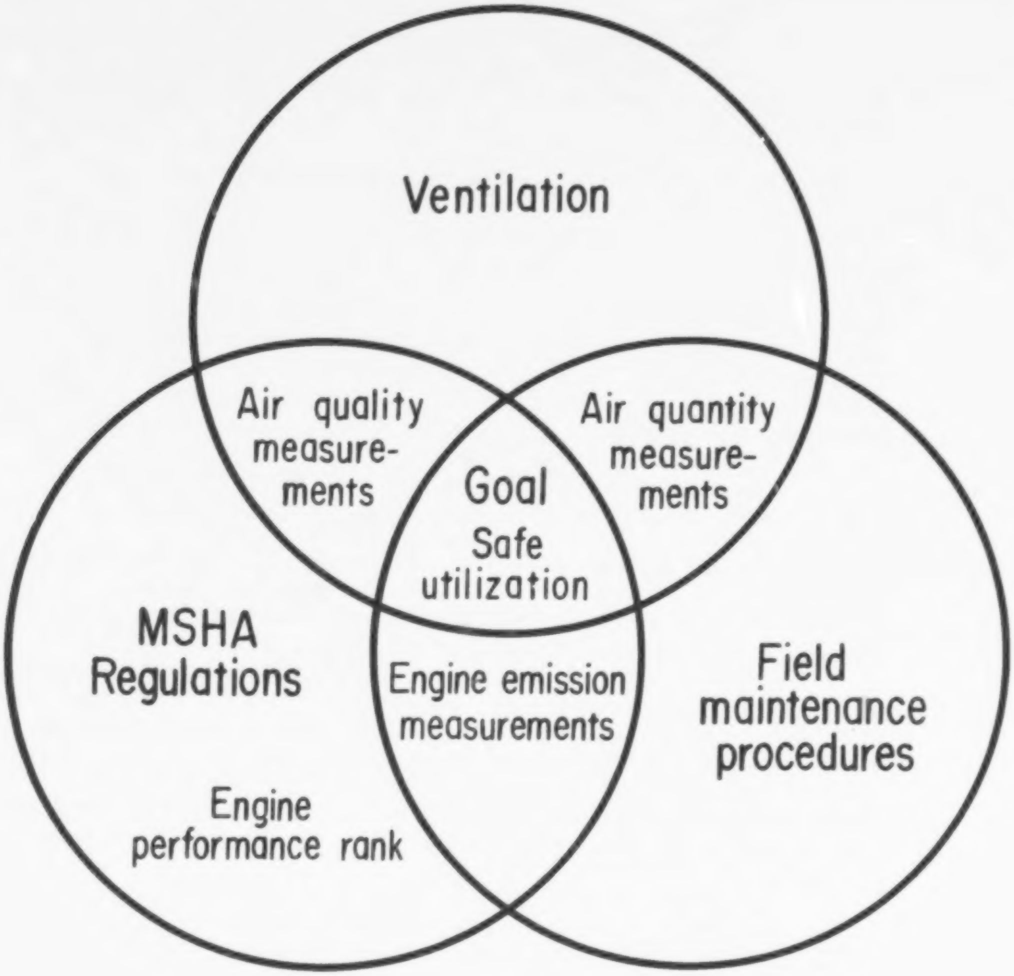
The Bureau of Mines diesel research program is reviewed; completed and ongoing programs that address the areas of emissions control, emissions characterization, field studies, instrumentation and monitoring, and noise are discussed.

INTRODUCTION

The goal of the Bureau of Mines diesel research program is the safe utilization of diesels underground. The interacting parameters that must be controlled to achieve that goal are shown in figure 1 by the overlapping circles which form a triangle. The left-hand side of the triangle represents those Mine Safety and Health Administration (MSHA) regulations that specify the conditions for proper diesel operation in underground mines. For example, these regulations specify the quantity of dilution air, and hence the mine ventilation requirements, needed to obtain an acceptable air quality based upon the actual emissions from a particular diesel engine. The items in the base of the triangle represent the actual pollutant concentrations from the engine and its control system when new, during the deterioration of the engine due to use, and as affected by maintenance of the engine and its control system. The right-hand side of the triangle addresses the various alternatives for the control of emissions, and basically represents the operator's choice between better maintenance and/or increased ventilation to maintain the proper air quality.

The Bureau's research program is divided into five functional areas that address the points identified above. Specifically, these are emissions control, emissions characterization, field studies, instrumentation and monitoring, and noise.

#1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In the area of emissions control we have emphasized the evaluation of existing and prototype control systems and the development and evaluation of some innovative systems that are applicable to this problem. Examples of the types of emission control activities are described below:

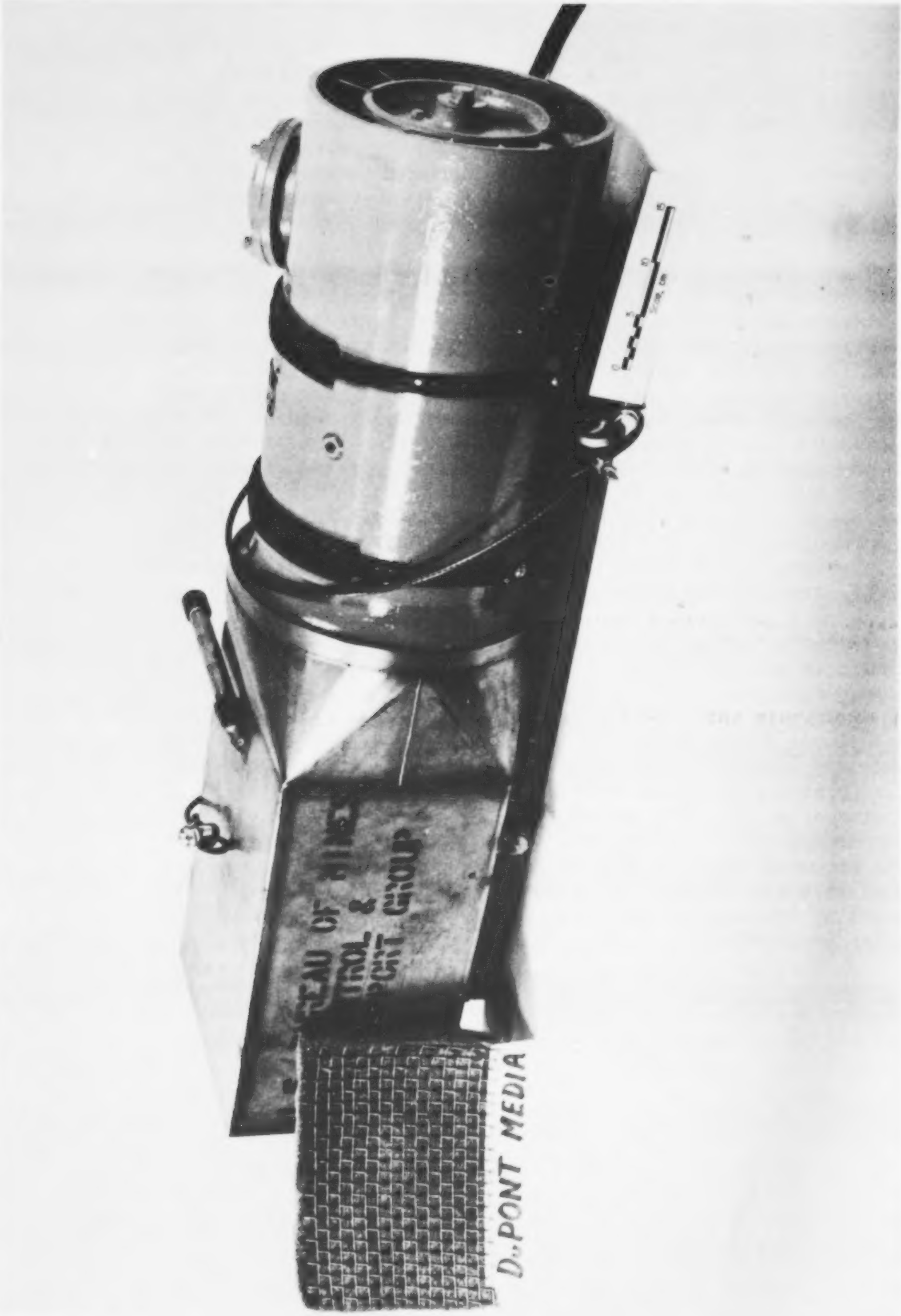
1. Catalytic: The Bureau has been accumulating data on gases and particulate emissions from various catalytic converters; as an example, comparisons have been made between the monolithic and pelletized-bed-type catalysts.

2. Scrubbers: Candidate scrubbing systems are currently under evaluation. These include the prototypes by Texaco and Ricardo Engineering and a wetted-bed scrubber which has been extensively studied by the Bureau's Respirable Dust Group for the control of respirable coal dust. The Texaco scrubber consists of an aluminum-oxide-coated steel wool bed. It has a minimum operating temperature of 850°F. Preliminary results show that particulate removal efficiency is about 60 to 70 percent. Some problems may be encountered as a result of an increasing back pressure as a function of long-term operation; this pressure buildup is currently under investigation. Additional research will be initiated this fiscal year to systematically optimize combinations of control devices for underground applications.

   Figure 2 shows an engineering prototype of a wetted-bed scrubber which has been extensively evaluated underground for the control of respirable coal dust. For that application the system is extremely efficient with particulate removals in excess of 99 percent. However, because the size range of diesel particulates is somewhat smaller than that of respirable coal dust, removal efficiency for diesels would not be anticipated to be as high. But the system has the unique feature of rather minimal pressure drop so modified configurations may be possible which could increase its efficiency in removal of the small diesel particulates. Laboratory trials are presently underway on this type of technology.

3. Alternate Fuels: We have been accumulating data on alternate fuels for the diesel engine underground, such as low-sulfur diesel fuels and other types of fuels such as methanol. At this time the only feasible emission control via fuels appears to be from the use of special low-sulfur fuels, and these fuels only reduce the sulfur component in the exhaust. Additional research is planned to examine in more detail the effect of fuel and lubrication oil composition on emissions.

#2



4. New Engines: We have under evaluation new diesel engine systems. These include a new exhaust conditioning system by Jeffrey and a new water-cooled Deutz engine on which the manufacturer's preliminary data show significantly reduced emissions from models previously evaluated.

5. External Combustion: We have been actively investigating external combustion engines such as a steam engine that will be used to power shuttle cars and Stirling cycle engines for application where reduced emissions are of importance. This particular technology, if successful, should result in emissions that are only about 1/10 those of a state-of-the-art diesel system.

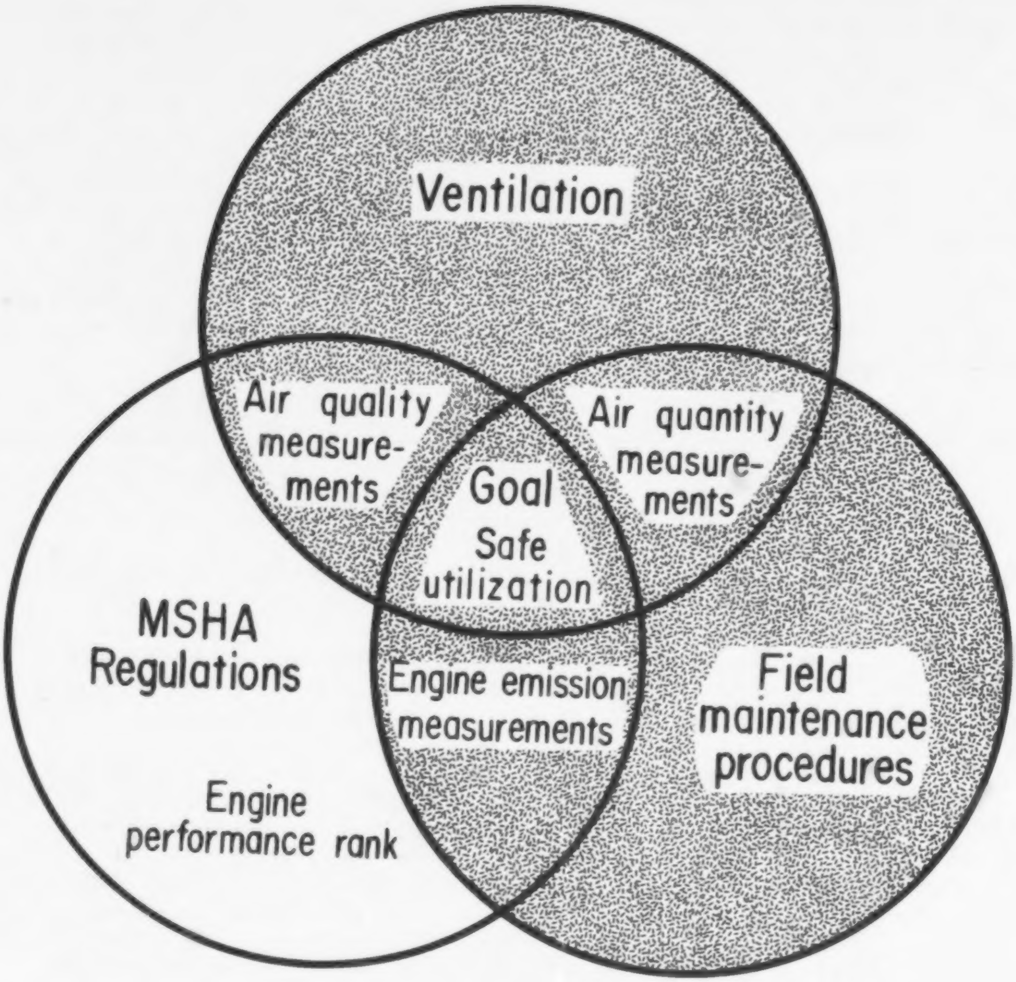
In the highlighted area of figure 3 covering MSHA regulations, the certification of new engines and the ranking of engine performance based on emission levels are the input parameters in the portion of the triangle that we are discussing. The rank of the engine, as determined by MSHA tests, is specified by the quantity of emissions that will result from this particular powerplant relative to others with the same approximate horsepower. The mine operator, knowing his power requirements, can then trade the emissions level against ventilation in order to meet safe working conditions. One should note that it is the highest observed concentration level of the toxicant relative to the accepted allowable level (8-hour time weighted average or TLV) for that species that controls the amount of dilution air required, and that somewhat surprisingly, especially with catalytic converters, it is not CO but rather NO_x or CO_2 that typically constitutes the limiting parameter.

Emissions characterization is the second category under active investigation. In the emissions characterization program the following work has been completed or is presently underway:

1. Analytical Procedures: The Bureau has emphasized the development of repeatable analytical procedures. These procedures have been successfully demonstrated in round-robin trials. Included in this work are SO_2 and SO_3 determinations and improved methods for determining polynuclear aromatics (PNA). The required time for some of the PNA procedures have been significantly reduced; of interest are the specific determination of benzo-a-pyrene (BaP), benzo-a-anthracene (BAA), and other polycyclics.

2. Laboratory Evaluation: Using these analytical procedures, laboratory evaluations of candidate diesel engines, including the emissions control system, have been underway.

#3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3. Field Studies: Principally through our program at Michigan Technological University, exhaust gas analysis under controlled load conditions in the field will be investigated. Hardware development for this investigation has been completed, and field studies will begin shortly. Earlier investigations have provided an assessment of the extent of the emissions problem in selected operations. Additionally, work will begin shortly on the effect of the mine environment on unstable and reactive species. Using a mine entry as a full scale, instrumented dilution tunnel the emissions from an engine will be mapped through the entry.

In figure 4 the highlighted portion of the triangle addresses measurement of engine emissions relative to certification and the effects of these in terms of field use. The deterioration of engines as a function of time and the type of maintenance is of importance in terms of the safe utilization of diesels underground. Through our field studies we expect to identify what happens to engine emissions in the field relative to emission levels obtained in the laboratory during certification.

As an example of the effect of exhaust conditioning systems, figure 5 shows emission levels of a diesel without an exhaust control and with two candidate catalytic exhaust treatment systems. This type of data has been obtained in more detail in order that we may quantify the performance of these types of exhaust conditioning systems.

In the highlighted portion of figure 6 of the triangle we represent the effect of field maintenance on the actual engine emissions. Preliminary data have shown that, even after overhaul at a field shop, there is considerable variability in the performance and emissions map of a used engine compared to its performance when received new from the factory. Additional data in this area from planned work will identify the critical factors of overhaul that require special attention.

The entire base of the triangle is highlighted in figure 7 to identify all of the factors that affect the diesel engine as a pollutant source. In summing up these factors are (1) its manufacturer and MSHA certified emissions when new, (2) the effect of use and age, and (3) the effect of maintenance.

The third area under investigation is that of field studies, which are addressing the following areas:

1. Sampling Procedures: Our research program is directed towards determining what, when, where, and how to sample in order to develop the methodology that can be used to assure that safe working conditions are maintained for all personnel underground.

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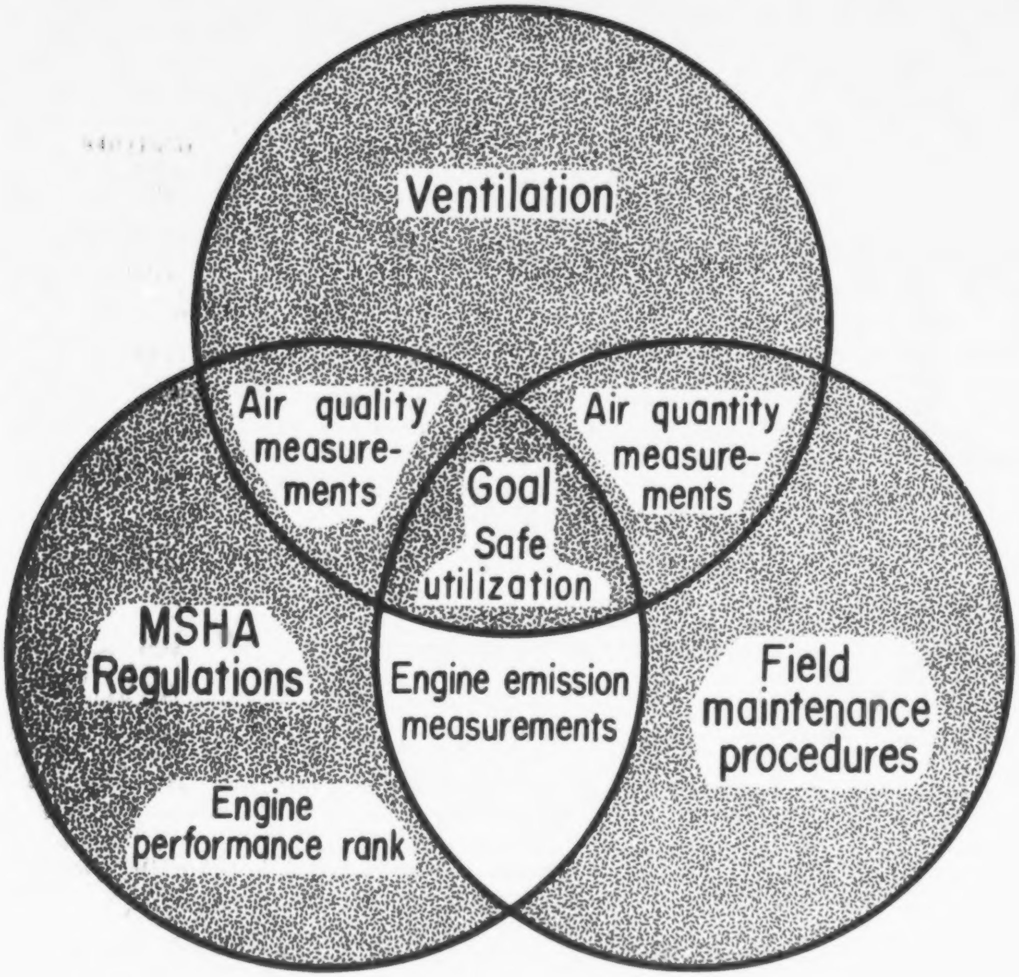
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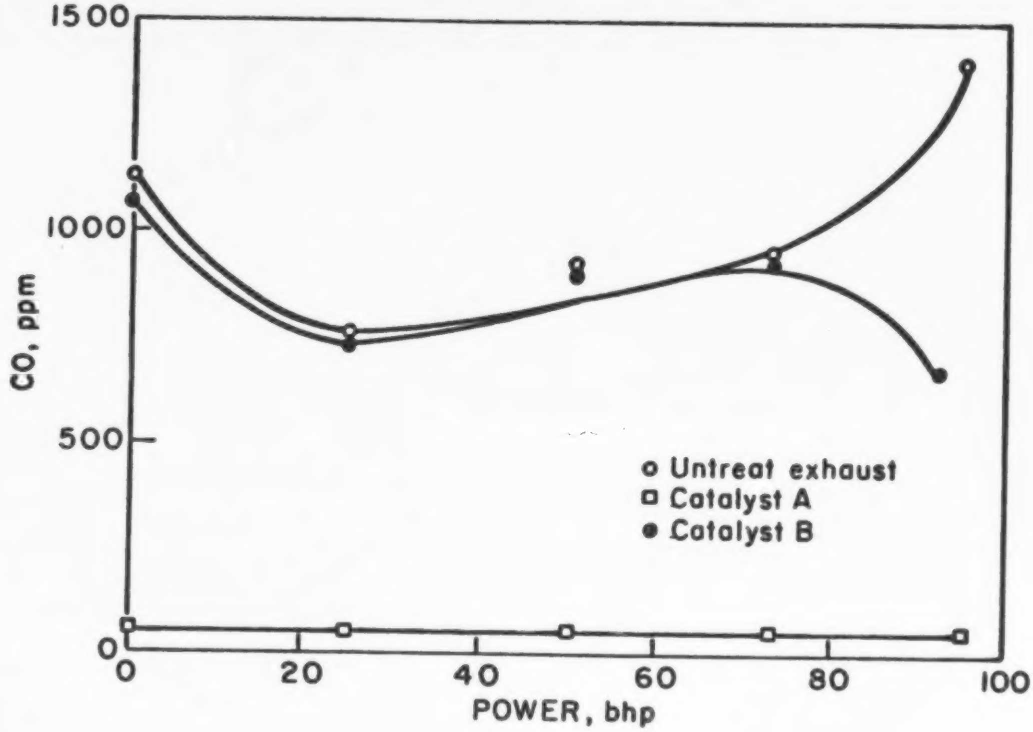
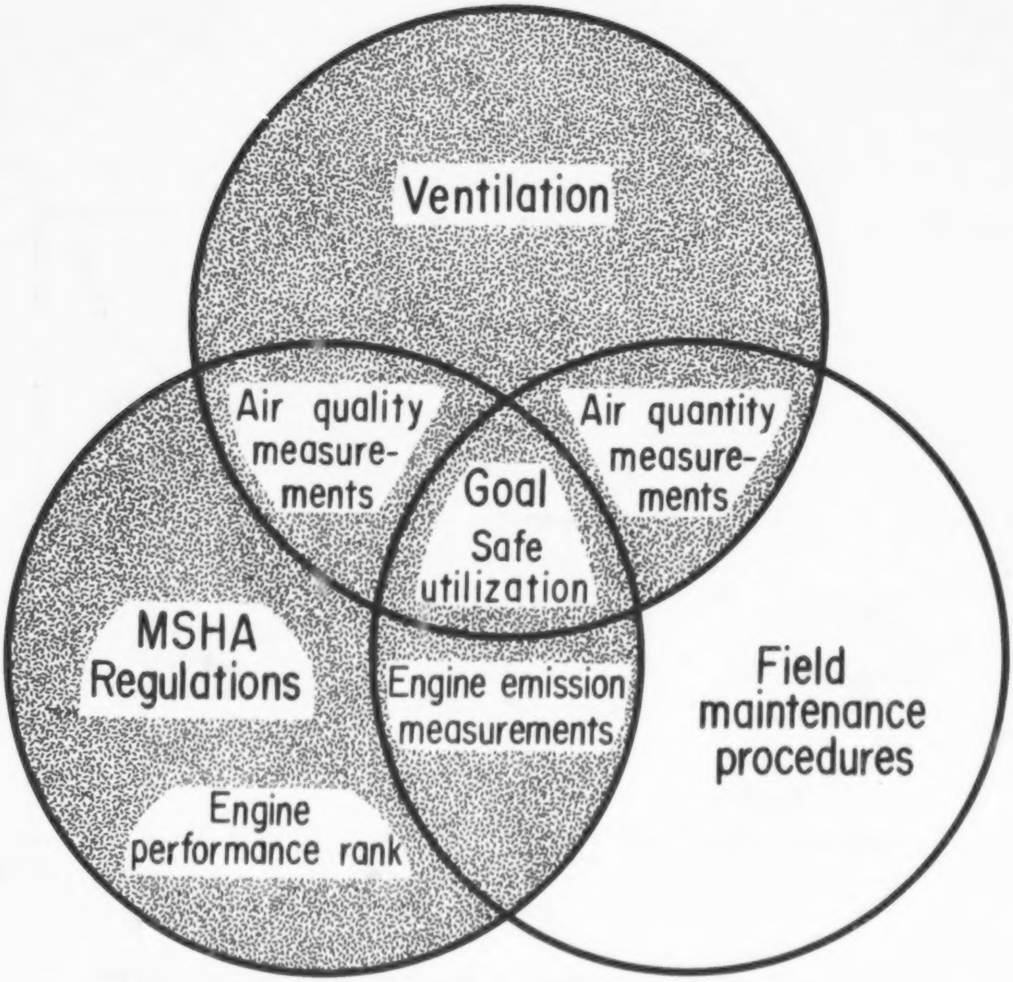


FIGURE . - CO emissions vs engine load at rated speed (Engine 2)

#6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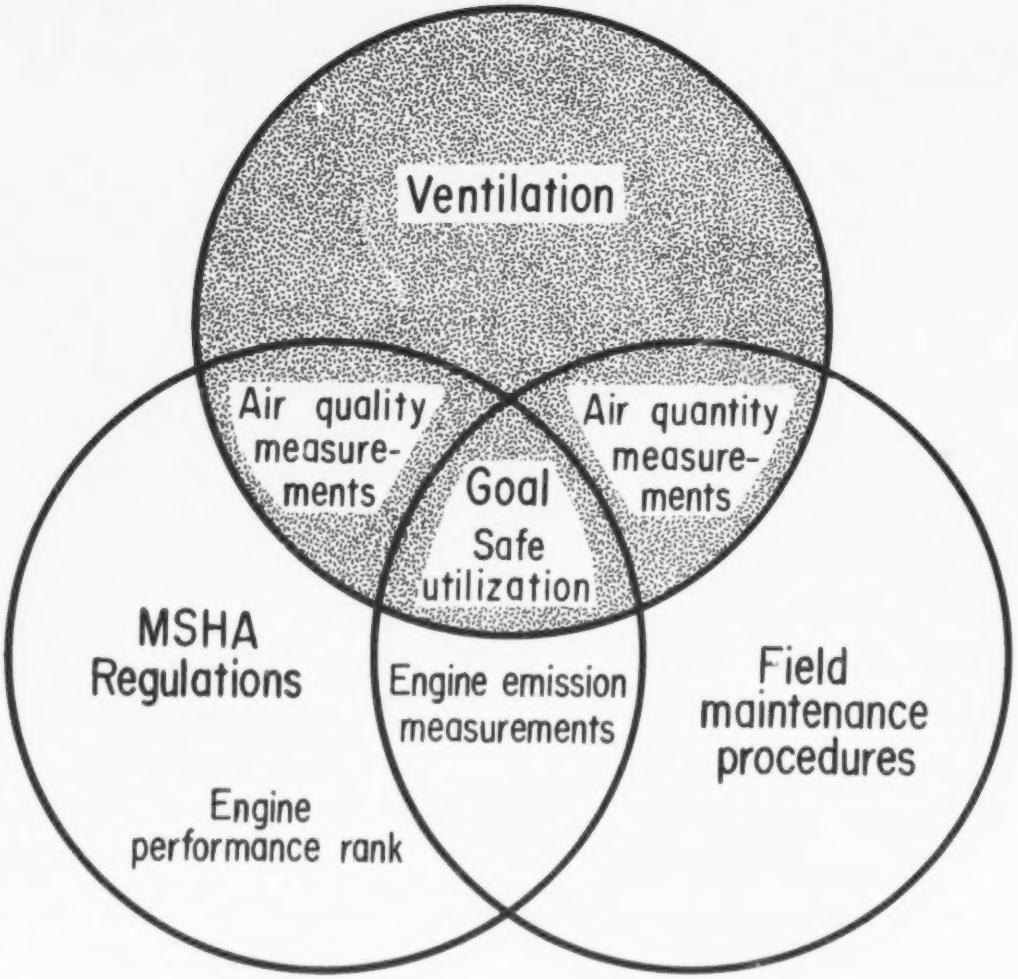
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2. Instrument Evaluation: In addition to supporting the development of sampling procedures and methodology, the field studies provide an opportunity for the evaluation of developmental instrumentation with encouraging results that will be described in more detail below.

3. Ventilation: Studies include the effects of dispersion and dilution and the field validation of analytical studies of ventilation models. Much of the work is being done in metal as well as coal mines because of the availability of diesel sources in a variety of ventilation systems. One point of interest is that the results to date show that some of the emission components that are measured in the exhaust stack do not appear in the mine air. Investigation of how these substances are being absorbed or their concentration reduced is the subject of further study.

4. Methodology: As discussed above, this emphasis is on how to sample effectively and to use computer models for air quality prediction and ventilation planning and the verification of both in the field.

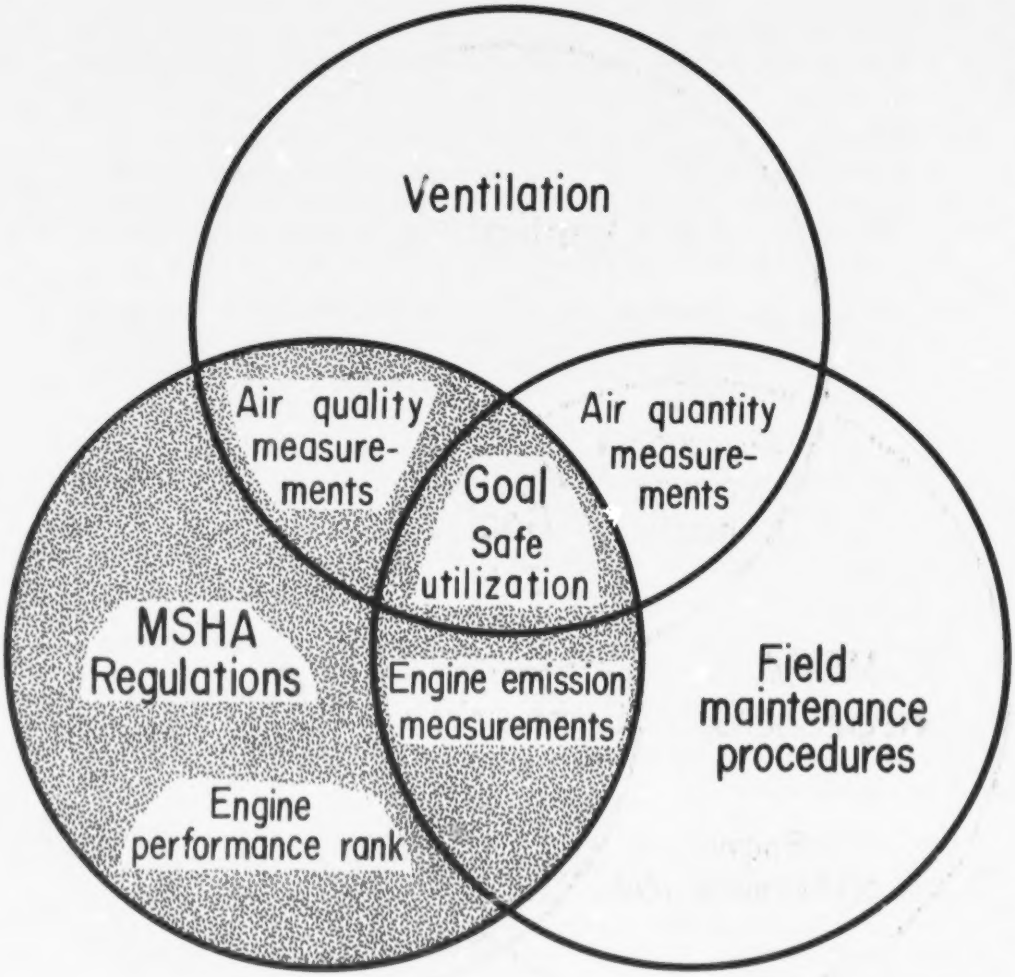
The majority of the measurements are being taken by Michigan Technological University under Bureau contract; work has now proceeded to study similar situations in dieselized coal mines. Included in this work is the in-mine assessment of handheld and portable instruments and the development of sampling methodology through analysis of the measurements.

Two aspects of exhaust emission control are ventilation and workplace air quality measurements to emphasize their importance in meeting the objective of a safe and healthful working environment. Figure 8 highlights the right-hand leg of the triangle and represents the tradeoffs that are available to the mine operator for obtaining and maintaining proper air quality.

The left-hand leg of the triangle, figure 9, pertains to MSHA approval procedures and to the ventilation air quality that is specified in the engine approval as computed from the emissions of the engine when new. The previous discussion has covered the point of this specified ventilation requirement in relation to the deterioration of the engine subsequent to the initial approval.

The next major area of Bureau research pertains to instrumentation and monitoring which is divided into the following areas:

#8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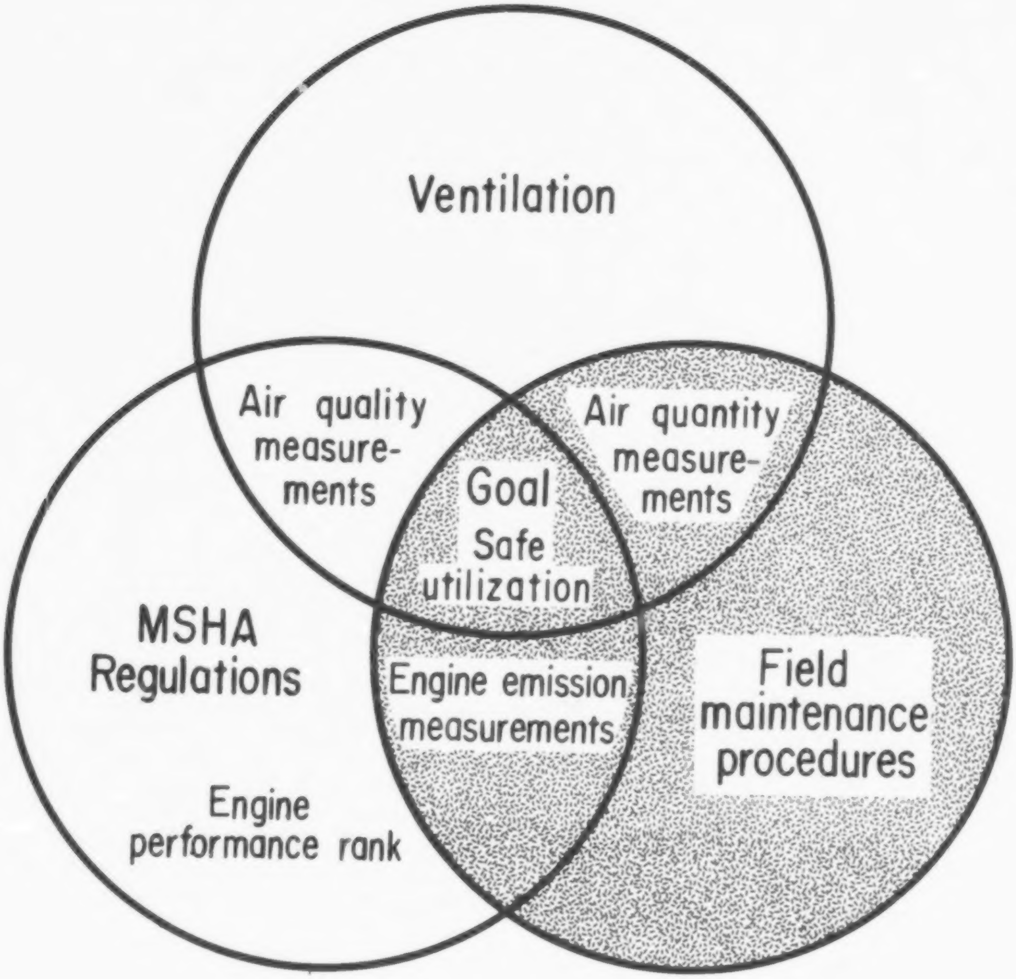
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1. Handheld: For spot inspections by company and MSHA personnel to ascertain air quality.

2. Dosimeters: To be worn by personnel underground to determine integrated quantity-level measurements for an entire shift.

3. Vehicle: For use on board vehicles to identify undesirable levels of toxicants, principally CO_2, in the vicinity of the vehicle and its operator.

4. Area: To be used with or in lieu of personal and handheld monitors to ascertain acceptable air quality underground.

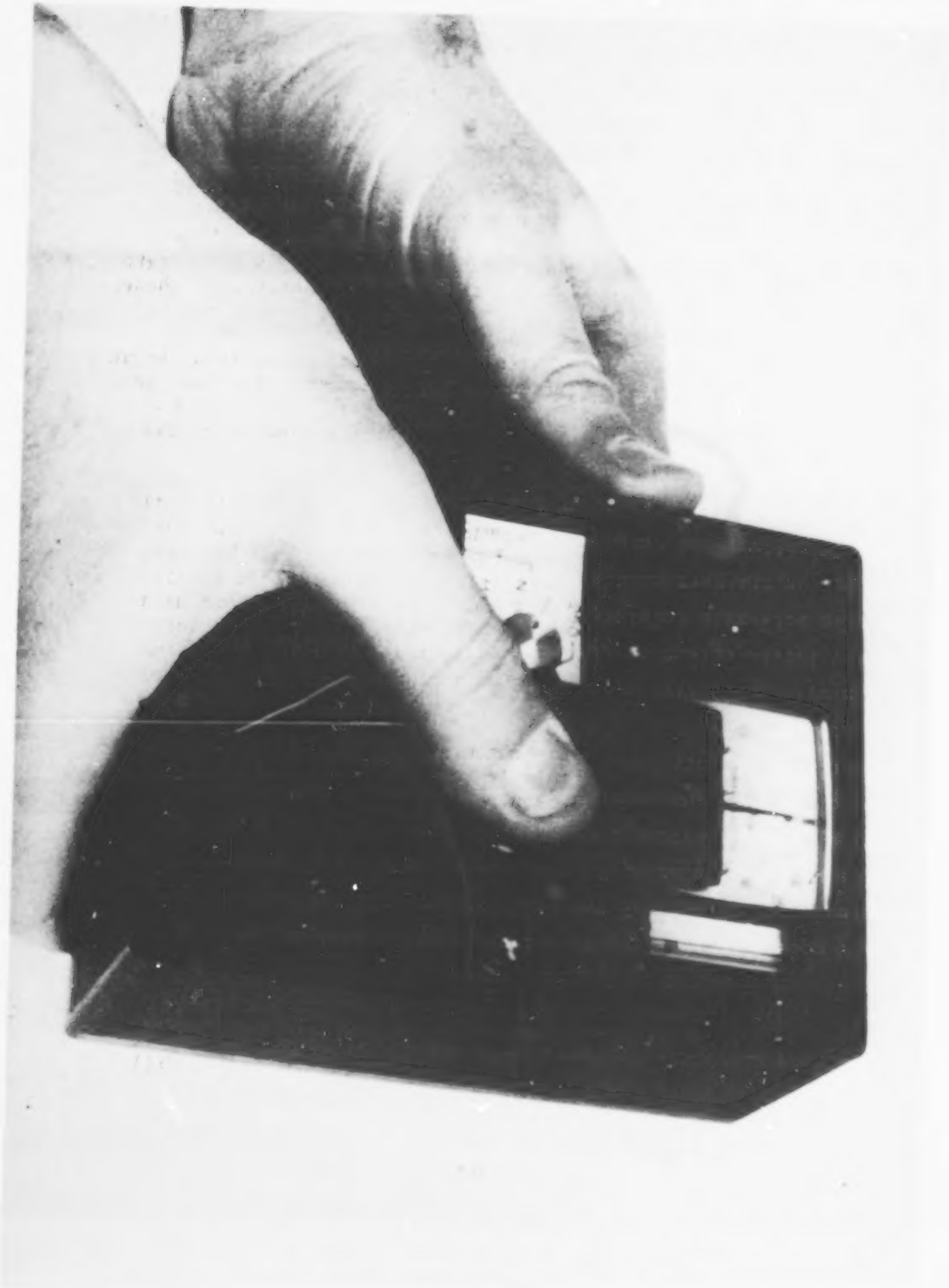
The primary device used for underground measurements is the length-of-stain tube. The Bureau has conducted extensive evaluations of these, and the overall error of the device under mine lighting conditions is approximately ± 25 percent; however, the significant portion of this error is due to the observer. The Bureau has evaluated an optical stain tube reader that significantly reduces the error; however, the cost and complexity of making measurements with length-of-stain tubes is substantial and has prompted the development of alternative means of gas detection.

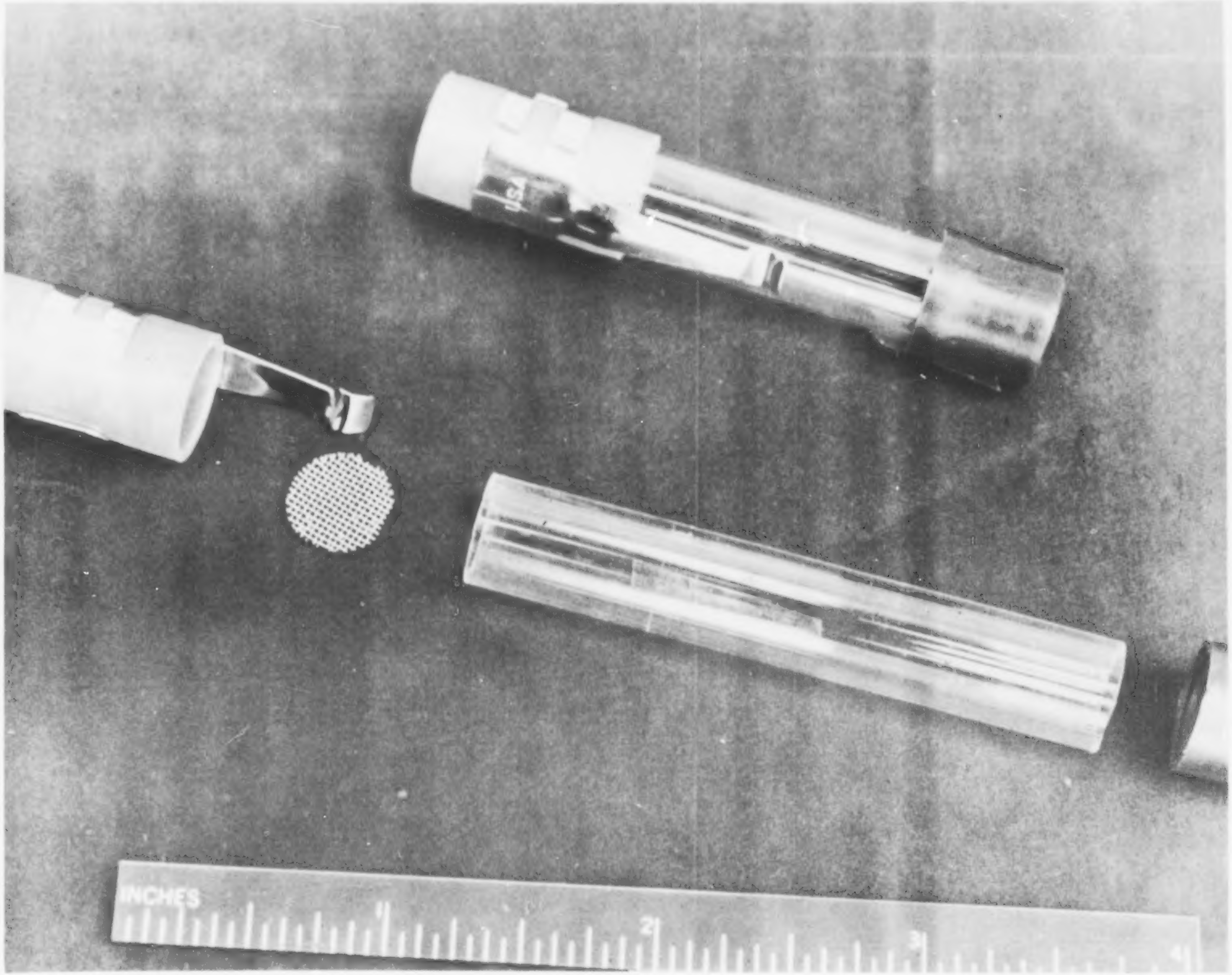
Significant progress has been made in the use of electrochemical sensors for the determination of underground air quality. Shown here (figure 10) is a prototype carbon monoxide detector (General Electric fuel cell) which has undergone extensive laboratory and field trials with excellent results; both stability and calibration have been maintained after months of underground use. The same type of technology is presently being adapted to other gases including NO, NO_2, SO_2, and H_2S. An alternate technology is being pursued for the measurement of CO_2.

The problems of underground instrumentation from a human factor viewpoint are considerable, particularly considering that for the foreseeable future each toxicant will require its own detecting device and dictate that every effort be made to minimize the size and weight of devices to be carried by mine personnel. Dosimetry is one approach to reduce package size. Shown in figure 11 is a nitrogen dioxide dosimeter that can be worn by the miner. At the end of the shift the device is analyzed to determine the dose of nitrogen dioxide obtained during that particular working shift.

Shown in figure 12 is a typical installation of a CO_2 monitor with the warning and meter display in the operator's cockpit; this device has been successfully evaluated in a number of operating mines. Several small engineering changes are being made, and the device will be used in extended underground trials.

#10





HY-4

#12

H4-8

The Bureau has an extensive program in area monitoring, and figure 13 shows one device developed under Bureau funding that is now commercially available. This particular station monitors three parameters; namely, air flow, carbon monoxide, and methane. Similar technology has been adapted to other system configurations and is being evaluated in operating mines.

The fifth area is that of noise control; the principal activities have been directed toward the identification of noise sources and the development of control procedures for same. In the case of a load-haul-dump, which is a commonly used diesel-powered vehicle, initial unabated noise levels are 98 to 100 dbA. After modification the noise levels were reduced to approximately 90 dbA. A noise control package for a Wagner load-haul-dump is now commercially available based on the results of this research.

In another example, a Getman dispatch vehicle was modified to reduce personal noise levels from 98 dbA to 88 dbA, which keeps the miners in compliance for an 8-hour exposure.

This paper has a brief overview of the Bureau program; in summary it consists of developmental engineering, analytical work, and field investigations; covering many of the areas as they pertain to mining to be reviewed by this workshop. We welcome the identification of gaps in these areas that should be addressed. This work, in conjunction with the epidemiological and medical work, should permit a positive assessment of the potential hzards and the development of adequate control technology for the use of diesel-powered vehicles in underground mining operations.

#13

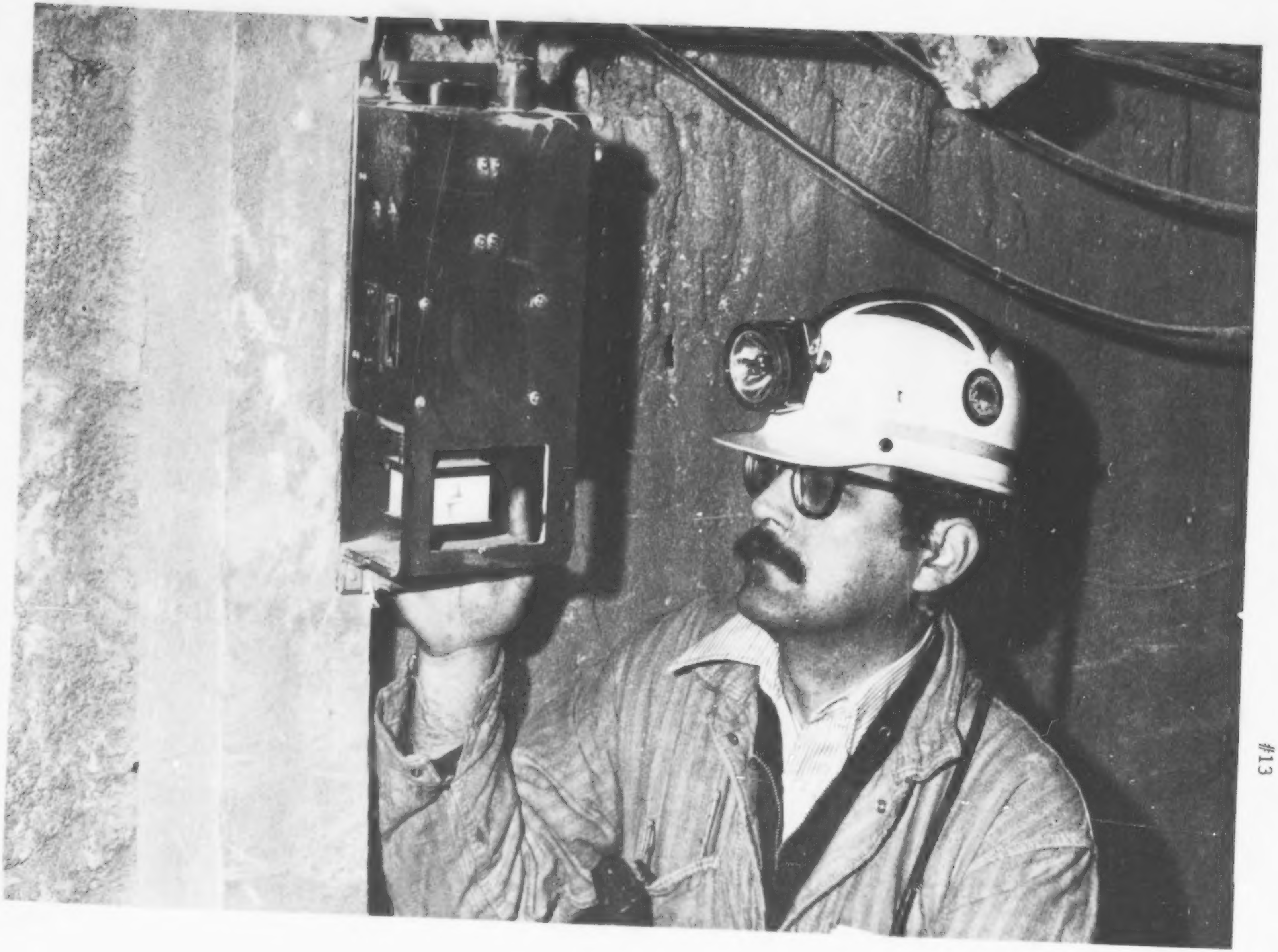


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Figure 2. Engineering prototype of a wetted-bed scrubber.

Figure 3. Highlighted area: The role of MSHA regulations.

Figure 4. Highlighted area: The effect of engine emissions.

Figure 5. Effect of two candidate catalytic exhaust treatment systems.

Figure 6. Highlighted area: The role that field maintenance plays in overall emission levels.

Figure 7. Highlighted area: The factors that affect the diesel engine as a pollutant source.

Figure 8. Highlighted area: The trade offs that are available to the mine operator to maintain proper air quality.

Figure 9. Highlighted area: The role of the approval procedures in the establishment of air quantity for a given engine system.

Figure 10. Prototype electrochemical carbon monoxide detector for underground use.

Figure 11. Nitrogen dioxide dosimeter for full shift exposure measurements.

Figure 12. Machine-mounted CO_2 monitor.

Figure 13. Mine monitor station which measures air flow, carbon monoxide, and methane.

(Slides not included.)

MR. MARSHALL: Thank you. Our main efforts at Bartlesville in dealing with diesels and underground mines are primarily directed towards determining the influences of engines, fuels, exhaust treatment systems, operating duty cycle, whatever, on the emissions.

I have a few bits of data with me today, and they will deal mainly with the effects of exhaust treatment systems on particulates.

First slide, please. This shows the effect of three different exhaust treatment systems, devices, on the size of the particulate discharged. I think the most interesting thing to notice is that in the center of each of the bars is the mass median diameter. The interesting thing to notice is that it does not vary very much from about, typically, 1/10 to 2/10 micron.

In these treatment devices, the traps are the Texaco-type traps. Catalysts and water scrubber. These systems are effective in removing particulate. The material that does come out looks an awful lot like what is going in in terms of size.

Next slide. This shows the effect of an oxidation catalyst on the PNA level of the extract from the particulate taken off the trap. The BaP peak is this one. You can see with the catalytic treatment, it is reduced quite a bit -- it is just this little shoulder. These are roughly true to scale. All these peaks do correspond to various PNA's as well.

Next slide. This final slide gives some indication of there not necessarily being a good correspondence between the amount of particulate removed and the reduction in PNA levels. It is apparently a very highly mode-dependent phenomenon for exhaust treatment systems. Let me give you some idea of what these things mean.

With just catalytic treatment, this happens to be for an idle, no load condition, you can see we are effectively moving quite a bit of BaP component, 50 percent, with very little effect on the particulate mass loading. Additional treatments essentially at the same mode show that you do not necessarily have to have correspondence between BaP removal, PNA removal, and mass loading.

As we go up in exhaust temperature, in effect higher operating power conditions, we start to approach 100 percent removal of the BaP component and close to that of the total PNA component. These correspond to exhaust temperatures of the order of 800 to 1100 F.

Removing effectively all the BaP with catalytic treatment, with very little effect on the particulate mass loading, the inner trap acts as a catalyst in this case; as well, it removes 50 percent of the particulate and all the PNA and BaP and combination of catalyst and trap -- well, essentially 100 percent BaP removal with about 50 percent of the total particulate.

That is all. Thank you.

MR. HURN: Thank you, Bill. Those particular data were selected after Bill left to come up here, not knowing that he would in any way be participating in this. I think they were selected just as illustrative of some of the results that we have obtained in after treatment devices and to give some indication of what order of magnitude effect we have seen in our mine work.

We have some time left for a panel response. I believe that it might be useful for the afternoon speakers to assemble at the front, if nothing more, than to remind you of who they were.

While the gentlemen are assembling here, let me, again, remind you that there will be a continuing session in the morning, starting at 8:30, and this section given over to a discussion of factors affecting human exposure. Also, I call to your attention again that Joan Claybrook and Dave Hawkins will be here to give you some wordslon, I guess, their agencies' attitude toward, or viewpoint on or concern for the diesel problem. I am sure that you know Joan Claybrook represents DOT and its interest; Dave Hawkins, EPA.

Well, gentlemen, we have come to this point where you can address your questions to the panel, and I believe it is appropriate that we move right into that and let us entertain questions from the floor. The panelists will have adequate opportunity to provide whatever response they might wish to other presentations made this afternoon. Questions from the floor?

MR. HAFLEY: Joseph Hafley, Caterpillar, I have seen it said, at least in one place, that since diesel fuels are high in sulfur relative to gasoline, but that only two percent appears as sulfates, the rest of the sulfur in the fuel is naturally attached to the particulate, and this is a matter of concern. My question is, what happens to the rest of the sulfur in the fuel if it does not come out as sulfate? What does it come out as? It certainly is not destroyed.

MR

MR. HURN: Who would like to take that? John.

DR. JOHNSON: I think that most of it comes out as SO_2, but we have made some measurements in the tunnel, and we get fairly good balance. Other people, I think, Karl Springer might want to comment about that; but most of it goes out as SO_2. Probably, later on it converts to sulfate out in the atmosphere, also; but I think out the tail pipe, most of it is probably SO_2.

MR. WHEELER: I think this is quite an important point because a lot of the SO_2 ends up on the carbon, and when I mentioned this morning about the thermogravimetric analyzer, I expect that some of the weight loss which I said was hydrocarbon is, in fact, SO_2. Also, there are some medical effects of SO_2 on soot. There are some differences in how SO_2 attacks the lungs in the presence of carbon, which I expect is really best left over to tomorrow's session.

MR. HURN: Someone else have a question or comment? Let me pose one here. Some others of you might be mulling over what you wondered about earlier. There was data presented that showed the measurement levels of particulates much more consistent with the turbocharged engine than with the non-turbocharged. I noticed this and wondered if you have an explanation.

MR. SPRINGER: Do you mean repeatable?

MR. HURN: Yes. No, this was from Mr. Cornetti's work, was it not?

MR. WHEELER: No, it was from VW.

MR. LIES: We have one result from -- we have a Rabbit diesel, a normal Rabbit diesel, and test it with restore charging.

MR. HURN: Well, the measurements from the turbocharged engine showed much less deviation in measurements.

MR. LIES: Yes, about 20 percent smaller.

MR. HURN: Yes, do you have any explanation?

MR. LIES: That is only first results. We do not yet know.

MR. HURN: Well, somewhat — well, not on the same line, but I did note that there was mention of the ambient temperatures that were covered, and some of the work on the diesel emission -- this is yours, Karl, I believe, right? Did you use, or did I misunderstand, did you show a high average in median ambient temperature in your work, or did I misread the slide?

MR. SPRINGER: The temperature data was obtained on the highway, driving those two driving cycles. Our concern was that it was not as high as we would have liked. I think this really puts the collection and after treatment of diesel particulate from a passenger car into perspective. These driving cycles are not heavy duty cycles, and that is the crux of trying to use thermal burnoff. That was the point I was trying to make with that slide. The other approach is to locate the trap in the coolest part of the system that you can.

That is the reason for putting the large cannister back at the rear bumper. If I could, while I am speaking, there was one point brought up in John Johnson's presentation where he was using data from an SAE paper that was given about six months ago, I believe. There is -- and I have to add with what Dick Wheeler said earlier -- there is no good evidence that the use of barium, or calcium-barium type smoke suppressant additives reduce particulate weight.

I think that is a fallacy in that report that was quoted by John, and I would like to have the record set clear on this. Even the manufacturer of the additive agrees with data that we have already published that shows that when you use barium or barium-calcium additives, that the particulate, the gross particulate, goes up, not down.

DR. JOHNSON: Karl, you either disagree with American Oil -- you do not disagree with me -- but I think the data stood by itself. I think under some of the load conditions, the particulate did increase; and it showed that in some cases, it did decrease at full load. I think with some engines, depending on how they are developed, this can indeed happen.

I think the point that I was trying to make is that there are different things happening with different situations, and I think the data is correct from what I have read of your work and of their work.

MR. SPRINGER: We have an obvious inconsistency.

MR. DIMICK: I might mention, our experience when we ran with barium also confirmed what Karl is saying.

DR. JOHNSON: I think the data did show that at light load, that it increased. The barium contribution was shown on the figure, and I think it did show at full load that there was a net decrease of mass for this particular engine. I think that,can happen.

MR. WHEELER: Perhaps I would like to mention that we have tested a large number of additives which are alleged to clean up diesel exhaust. These are sold all around the world under all sorts of names and have all sorts of claims for them. We have never statistically shown any advantage in any of them, except the barium type.

The ones which I think Dave Dimick said that he had 5 or 15 percent improvement with, may be at the time we did it, we might not just have shown that, but we certainly would have shown a 20 percent improvement. Again, getting back to Dick Hurn's remark about why the turbo blowing was consistent and it had a good effect, we are also running quite a lot of work witht turbo blown motors, a and we think that there is a very big advantage in getting the poor performance of a diesel back with a limited amount of turbo blowing and this can compensate for the loss of performance with EGR.

We are running an engine on programmed EGR with the loss of power, being brought back to its standard level with turbo blowing. In fact, the particulates are not quite so badly affected when you do this. They are still worsened slightly,but not to the extent that you get with straight EGR.

I think there is something here in the way that the droplet evaporates. You have got more air, there is more oxygen availability in a turbo blown engine, as long as it is not pushed to its limit with power. Another thing we did was we tested a lot of oxygen additives, a lot of additives which are, in fact, cetane improvers,but do contain labile oxygen.

We would have expected these to do something to the particulates. The idea was that when the oil, the diesel oil, droplet evaporated, the oxygen compound concentrated in the drop as it reduced in size; and then, finally, when the drop wanted to convert into some soot, it had a lot of oxygen there with it. In fact, all it did was to reduce the soot exactly in proportion to the reduction of power by the addition of these materials which lowered the calorific value of the fuel.

MR. HURN: This will be about your last chance to confront these gentlemen. The discussion tomorrow will go into the health effects side; so, if you have any curiosities about the subjects discussed today, you should surface them now.

Let me ask one other question that I think might interest a number of you. We have done work that shows quite serious degradation in fuel economy with decrease in ambient temperatures and, also, with marked elevations of ambient temperature. I believe Dave Dimick alluded to this, and maybe Chuck Elder, the fact that the diesel did not show such severe deterioration in ambient temperature, at least a cold start efficiency was better.

My question is, do you have any feel for the overall improvement in economy that might be attributable to the decreased lack of sensitivity to ambient temperature changes with the diesel? Can you give a feel at all for this, Dave? Has the pencil been put to the numbers there?

MR. DIMICK: You are quoting Chuck Elder, and what he was referring to is that you have a much more urban type of driving and less of the city driving, that you do not have the cold enrichment that we have in the gasoline engine; and, therefore, the fuel economy is improved. Now, maybe Chuck has some figures along those lines. I do not.

MR. ELDER: If you are looking at something of very short trips, and I think I would put it in the context of very short trips, something on the order of three-mile trips, you can see 60 to 80 percent better fuel economy with the diesel than the gasoline.

It does depend on the design of the gasoline engine and how quickly it warms up, because it tends to warm up the oil faster, so there is a point where you can say maybe the diesel was not doing as good as the gasoline; but for the short trips, those are the ones that really hurt you, they really use up a lot of gasoline, a lot of fuel. The diesel does do an awful lot better.

MR. HURN: This is a particular point that I will want to look into further, and I would suggest that it might be profitable area for all of us to look into. I believe, my numbers might not be correct, I believe that something approaching half of the fuel consumed by U. S. passenger vehicles is consumed in making trips of something under 10 miles, and I believe, possibly under eight miles. Is that about right?

MR. STROMBOTNE: I think the average trip length is around 10 miles.

MR. HURN: Yes, and I believe because of the decreased fuel economy at the short trip length, you will find that something over 50 percent of the fuel consumed is in trips that are very, very short. So this might warrant more in-depth analysis.

Gentlemen on the panel, have any of you questions to ask or challenges to make to your associates here at the front table?

Well, thank you very much. Dick, have you or any of the DOT people closing remarks for this afternoon?

MR. STROMBOTNE: No, I just want to reiterate my statement of this morning, thanking all of you for attending, especially the gentlemen who appeared this afternoon and gave us their fine presentations. W

We will start again tomorrow at 8:15 — 8:30, rather.

MR. HURN: 8:30. That concludes the afternoon session. Thank you.

PROCEEDINGS

MR. GROBECKER: I would like to open this session of the Workshop on Unregulated Diesel Emissions and their Potential Health Effects, and this is Section C of that Workshop, concerning itself with Factors Affecting Human Exposure.

My name is Alan Grobecker. I am surrently with the National Science Foundation, but I am a one-time DOT employee who remembers fondly concerns with the automotive kind of problem. My particular task in the National Science Foundation is as Director of the Atmospheric Sciences Division, and of course, in that connection I am looking at the problems of pollution from the other end than from the automobile but one which is perhaps directly concerned with the subjects we are talking about this morning.

I would like to suggest to you that you note a change in the agenda which you may have in your hands. The speakers that are listed or the papers that are listed will be given in the following order, that is Karl Van Cauwenberghe's Atmospheric Reactions of Particulate PAH and Some Biological Implications will be number three. Ivor Tombach and Michael Chan's paper on Diesel Exhaust and Air Quality will be number one. John Heuss of General Motors will speak for Charles Begeman on the subject of Atmospheric Chemistry of Primary Particulates which will be number four. Joe Sturm of Transportation Systems Center, the Impact of Light Duty Diesel Vehicles, an Assessment Overview will be number two and Philip Levins of A. D. Little, Effects of Diesel Engine Emissions on Coal Mine Air Quality will be number five, and Richard Wheeler of Ricardo in Britain will conclude on the subject of Human Impact of Particulates from Different Sources.

I would like to ask if we can complete all these discussions by 11:15 which would allow an hour for the panel discussion in which hopefully there is a multilogue or so between members of the panel and the members of the audience.

There will, also, be a break at 9 o'clock for a short period in which Joan Claybrook, the Administrator of NHTSA, and David Hawkins, Administrator for Air Waste Management of EPA and possibly a representative from the DOE may give you some views of their concerns with the diesel engine and its possible pollution consequences.

I think just by way of introduction the picture I have of looking at automotive pollution and its effects is that we have a very good handle on the processes and mechanisms within the internal combustion engine and its production of the recognized pollutants, of nitrogen oxides, oxidants and CO and so on.

That is a matter of controlling outputs and of knowing what they are and so on, and the state of knowledge as I understand it is excellent in that category of concern.

These pollutants when emitted from automobiles and so on then move out into the atmosphere and that atmosphere now begins to take charge of the processes which can go on with the concentrations which occur in the atmosphere tend to diffuse these pollutants in the form they are emitted, and they change with intermediates of immediate reactions of very great variety, and so we know considerably less about that second aspect which was discussed yesterday than we do about the nature of the pollutants when they emit from the exhaust pipe of the automobile.

I think an even weaker problem is the consequences of the resultant very dilute concentrations, now almost in the trace element category which these pollutants take in a relatively stable form and which can have adverse effects on people and animals and plants and so on. That is understandably difficult to deal with because the only really proper way to get at it, since you cannot deliberately set out to poison people and see how they react is because you have got to do it by epidemiological studies and these from an information theory point of view are based on very, very noisy data, and it takes a terribly long time to extract a meaningful signal out of that data. It takes a great deal of effort and control to make sure that you have sampled in an appropriate way, and so to a very large degree in this latter phase which is, I guess, in the coming session after this one, is probably the least well known.

The session which we are talking about I consider as one which is manageably well known but not as well known as I would like, and a good deal of the concern are things that you are going to talk about today.

So, if I can introduce now the first speaker to address some remarks, Ivor Tombach will present a paper which he and Michael Chan of Aerovironment, Inc., prepared, and the subject is Diesel Exhaust and Air Quality, Micro and Macro Transport Process.

Can I add in behalf of my DOT associates, can you make sure that copies of your vugraphs get in the hands of Sam Powel who is sitting up here in front and prepared to operate your vugraphs if you have them, so that the record may show the complete story.

Ivor Tombach?

MR. TOMBACH: Thank you, Mr. Chairman.

Ladies and gentlemen, yesterday we determined that diesel engines emit some pollutants and also, I think, got the impression that those pollutants are going to be pretty hard to control.

Today we are going to pick up sort of after the first 10 or 100-fold dilution and follow this pollution through the air up to, as Jim Pitts puts it, up to the nose and no further, in the morning session and maybe a little further in the afternoon session.

I am going to address what happens in the air from the physical perspective primarily. Some other people will be addressing the chemical perspective. So, I will comment briefly for the benefit of those who are not familiar with atmospheric dispersion on some of the aspects of dispersion in a somewhat quick and free-wheeling discussion and then try to present our ability to model atmospheric dispersion.

To do this I will present some examples, illustrative examples, and I will borrow fairly heavily from both the literature, as well as from work we have done in the area.

Because of some obvious parallels between the diesel particulate problem and the catalyst sulfate problem, some of the sulfate experiments will be discussed briefly, and I will try to extend the results to diesel particulates. The parallels, by the way, include several interesting factors. One is that both the sulfate particles from catalytic converters, as well as the diesel particulates, tend to be in the submicrometer diameter range which means, among other things that the particles diffuse (at least over shorter distances) much like gases, and another is that both of these types of pollutants are very hard to sample and filter artifacts are an issue of great concern in sampling methods.

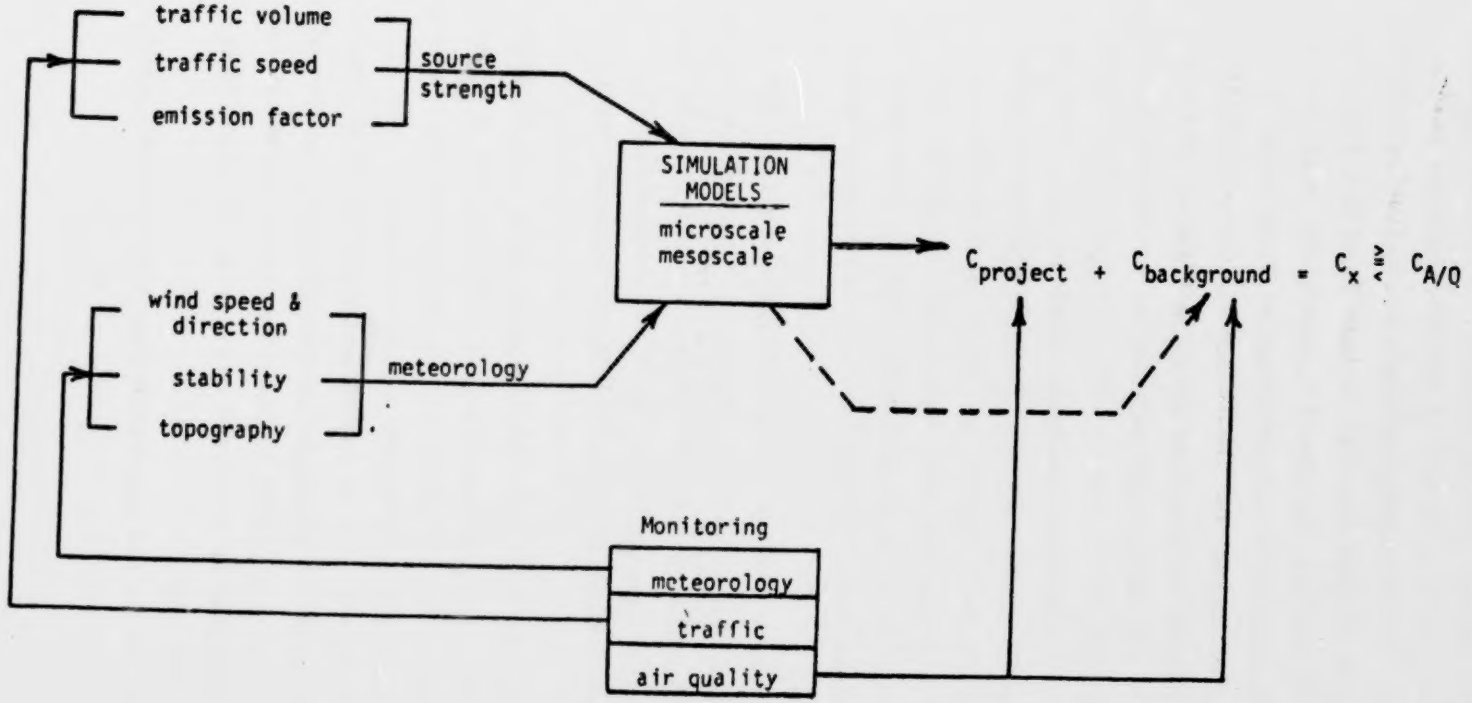
To back away a bit from motor vehicles, there are some analogues, also, that could be drawn between the approach that is right now being followed toward the treatment of diesel particulates and the approach that was followed starting maybe a decade ago for the treatment of particulate matter from industrial stacks. And there are possibly some lessons to be learned from what has happened over the last decade there.

About a decade ago or so most of the emissions standards for industrial stacks were based on opacity, just like the diesel situation is now, and looking at total particulate matter it was decided by the powers that be that total mass emissions should be regulated, and emission standards were established for total mass emissions from stacks.

This resulted in electrostatic percipitators being used widely, among other things, to control the particulate emissions. The result was that primarily the larger particles got controlled and the finer particles, the ones that affected health mostly, did not.

The consequence of this now is that some sort of other standard is going to be in the works or at least the handwriting is on the wall that there is going to be one within the next few years, be it for visibility or fine particles or sulfates, but any one of those three will accomplish the same end.

So turning back now to the automotive question if we can start #1



TOMBACH - 1

Interaction of Modeling and Monitoring to Assess Highway Air Quality Impact.

with the first vugraph, this is a reiteration somewhat of the slide that Jim Pitts showed yesterday, namely, another air pollution system. The main points to emphasize here are that we have emissions of some sort related to traffic (and they may be related to speed and the characteristics of emissions) which are acted on in an atmospheric system, or in a model simulating atmospheric system, which is driven by meteorology, particularly the wind speed and direction, the turbulence in the atmosphere (which is often simplified in terms of stability and topographic constraints which also govern the turbulence). These in turn result in some sort of concentration mix which quite often in actual application you try to monitor and try to have a feedback loop with control in it.

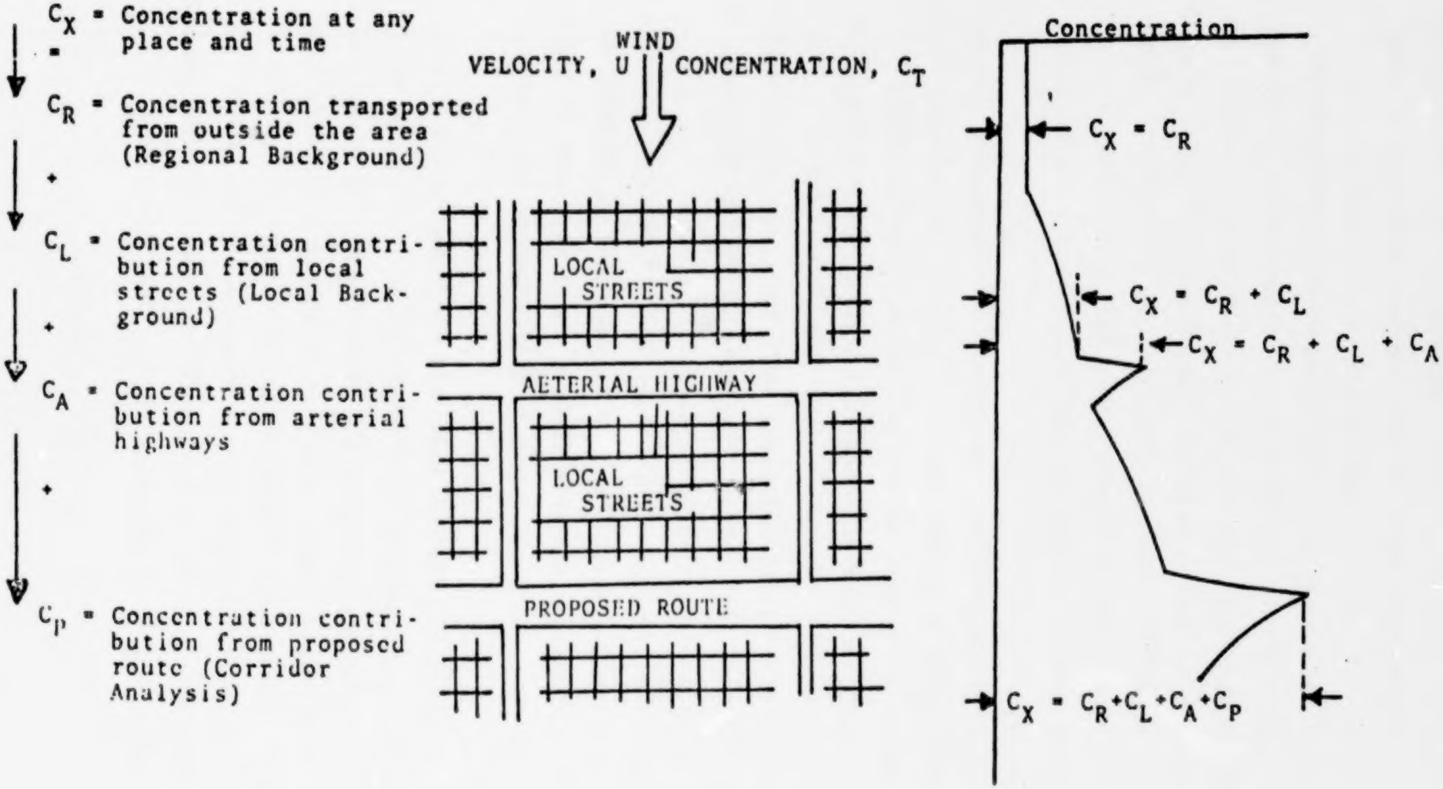
Moving on to the next slide, the atmospheric dispersion processes # 2 apply over a wide range of scales, starting from the microscopic scale of tens of meters. If we have an air mass moving down the page, there is a background concentration of pollutants coming into the area. It is first affected by small scale emissions from local streets. Then you may have a more-heavily traveled highway which has its own microscale air pollution impact reflected here, then more of this generalized emissions and again another microscale impact.

Microscale effects occur of distances of tens of meters. There is a larger scale,the mesoscale which is in the order of hundreds of meters or a few kilometers, and then finally there is a sort of macroscale which would be in tens and hundreds of kilometers that one is concerned with.

We will particularly discuss today the micro and mesoscales.

The next slide presents in very brief summary, for those who # 3 have never seen dispersion concepts, the whole concept of dispersion of pollutants from a line source, the line source in this case being a roadway. So, we have a nice two-dimensional situation, and the pollution is transported downwind as the wind blows. The cloud disperses upward, and in rough approximation the concentration profile ends up like being half of a Gaussian curve. Then there is a

Background Air Quality Definition



C_X = Concentration at any place and time

=

C_R = Concentration transported from outside the area (Regional Background)

+

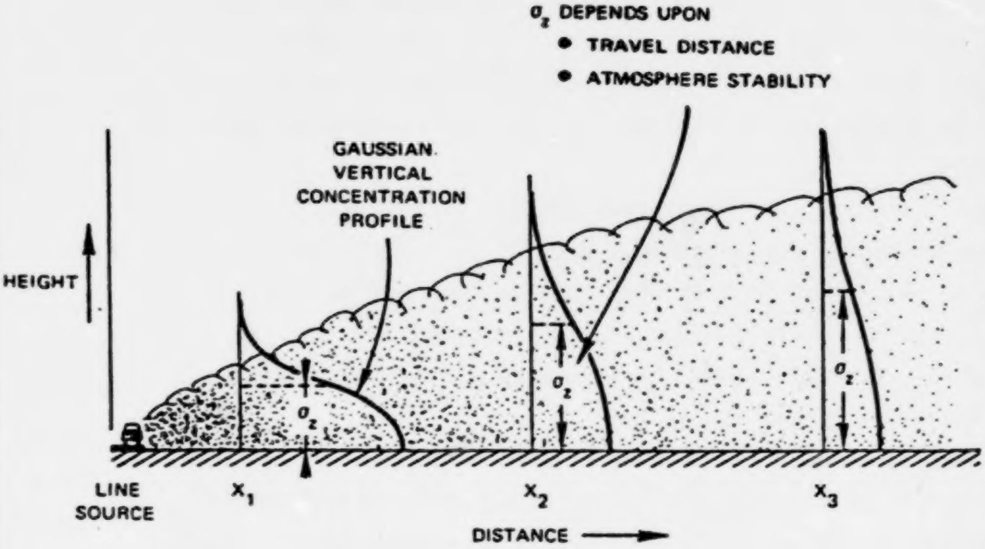
C_L = Concentration contribution from local streets (Local Background)

+

C_A = Concentration contribution from arterial highways

+

C_P = Concentration contribution from proposed route (Corridor Analysis)



VERTICAL DIFFUSION ACCORDING TO GAUSSIAN FORMULATION

Source: User's Manual for the APRAC-1A Urban Diffusion Model, September 1972 characteristic dimension, which in the case of a Gaussian distribution would be the standard deviation, and it is called sigma Z, which is used sometimes in some formulations to describe this plume.

The next slide shows what kinds of results one gets when you are treating microscale dispersion from highways. The horizontal axis here is the distance downwind from the roadway edge to this point which is the roadway edge, and the vertical axis represents the concentration. #4

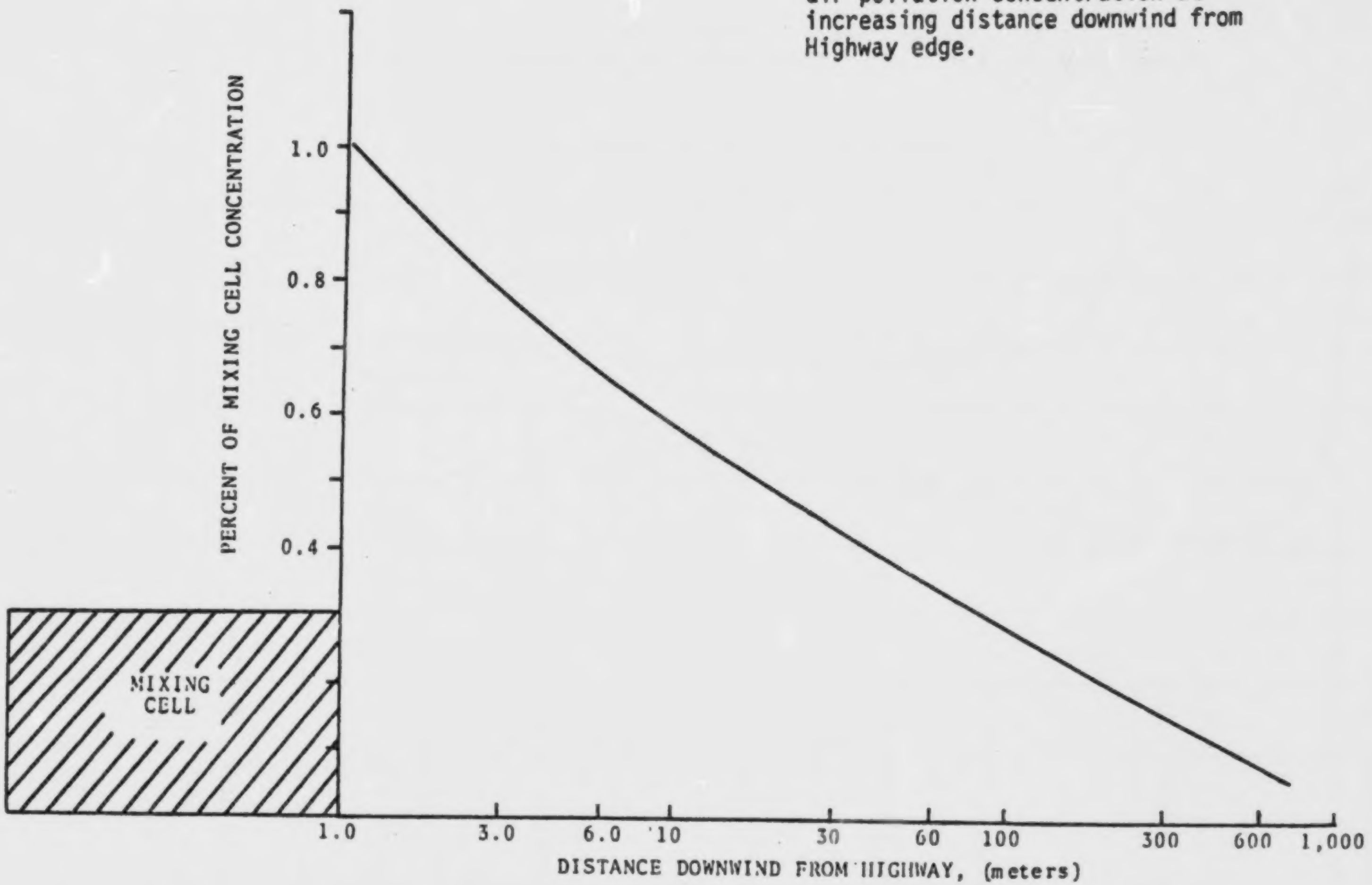
Around the roadway there is a cell where the pollutants are very well mixed by traffic and by the buoyancy of the exhaust gases, and then as this parcel of air (which tends to be of a height characteristically maybe twice the height of the vehicle stream if you have got a dense vehicle stream, not if you have got one car every mile) disperses downwind.

Now, the concentrations decay very rapidly with distance. I think the big important point is that typically the concentrations have dropped to 50 percent of what they were on the roadway in a distance of around 10 meters from an isolated roadway. It is very rapid dispersion. It will change somewhat with atmospheric conditions, but that is the order of magnitude.

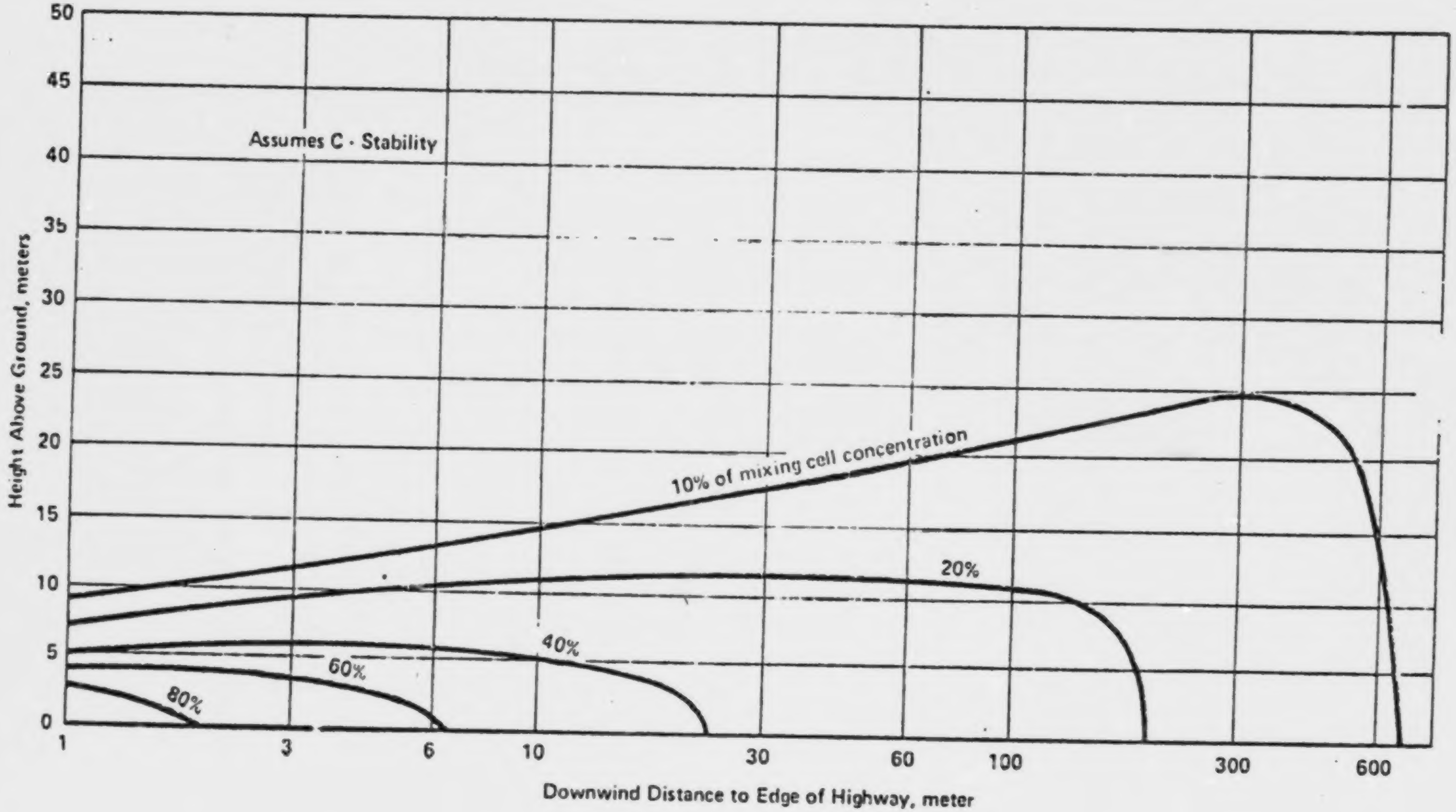
The next plot shows the same kind of information presented in a slightly different way, against the downwind distance and the height above the roadway, in terms of lines of constant concentration. Again the 50 percent concentration line at the surface is at about 10 meters, and the cell is 4 or 5 meters high at the roadway edge. #5

The next slide presents some real data with another model. In this case it gives some numbers which are for carbon monoxide, but you will recall I said that the small particles disperse very similarly over this scale. It again shows that the decay is very rapid. #6

This particular case is for an arterial roadway in a low background area. The background concentrations are quite low at the edges, and you have a fairly high impact with a case of rather low dispersion. One can convert these numbers sort of mentally to the

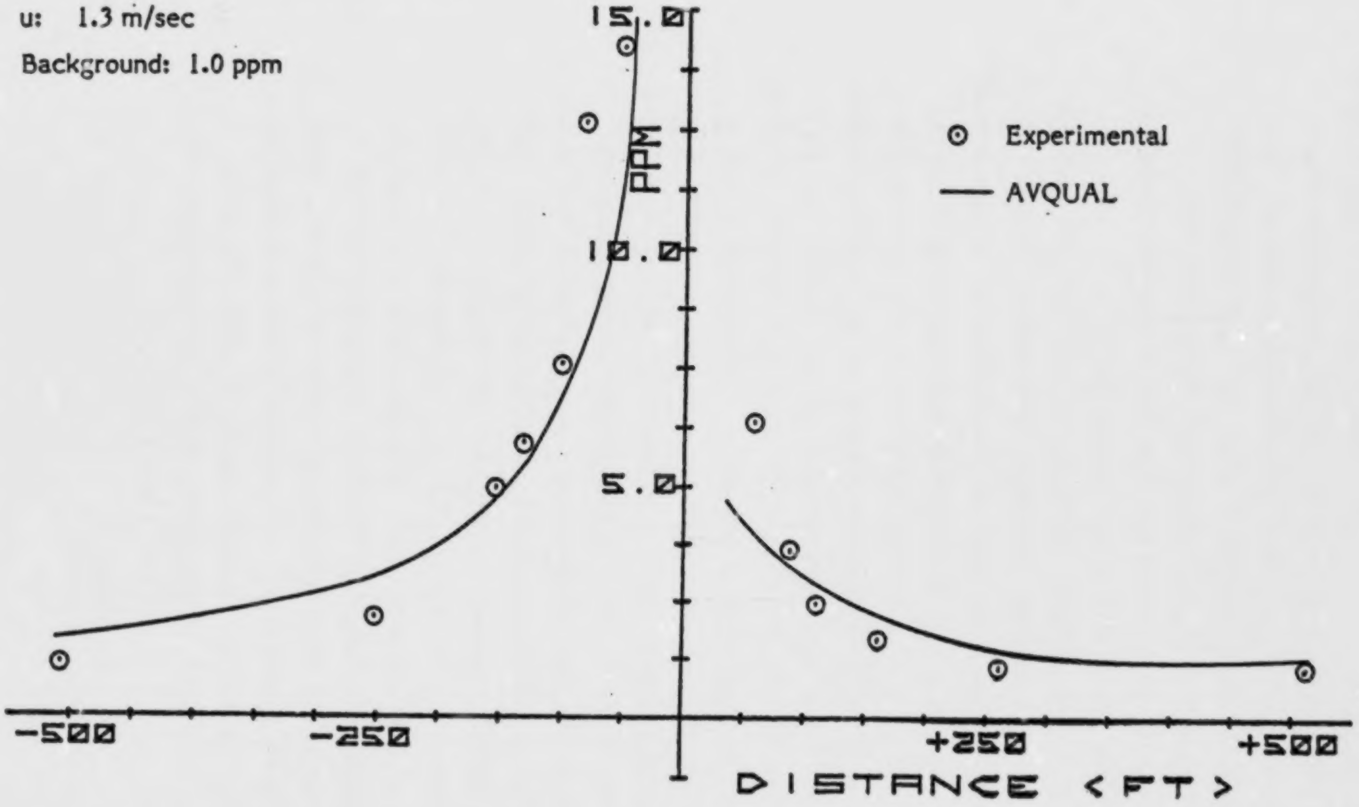


Decrease in ground level ambient air pollution concentration at increasing distance downwind from Highway edge.



Isopleth Concentration Lines Downwind of a Highway Line Source.
(California's Highway Model, At-grade Section)

Model Calibration II
Date: 2/26/75 Time: 1100 - 1200
u: 1.3 m/sec
Background: 1.0 ppm



Comparison of Measured (circles) and AVQUAL Predictions (triangles) of CO Concentration as a Function of Distance from the Centerline of a Roadway in Las Vegas, Nevada, During Low Winds in the Winter of 1975.

particulates that would be emitted from a diesel situation, and if one were talking about, say, 200 milligrams per mile of emissions of particulate matter which can either be 100 percent of the cars emit 200 milligrams per mile or alternatively 25 percent of the cars emit 800 milligrams per mile, which is sort of the ballpark we were talking about yesterday, these numbers represent the ambient concentrations of particulate matter in micrograms per cubic meter, roughly. So, we are talking about 15 micrograms per cubic meter of particulate matter near the roadway due to emissions from diesel exhausts.

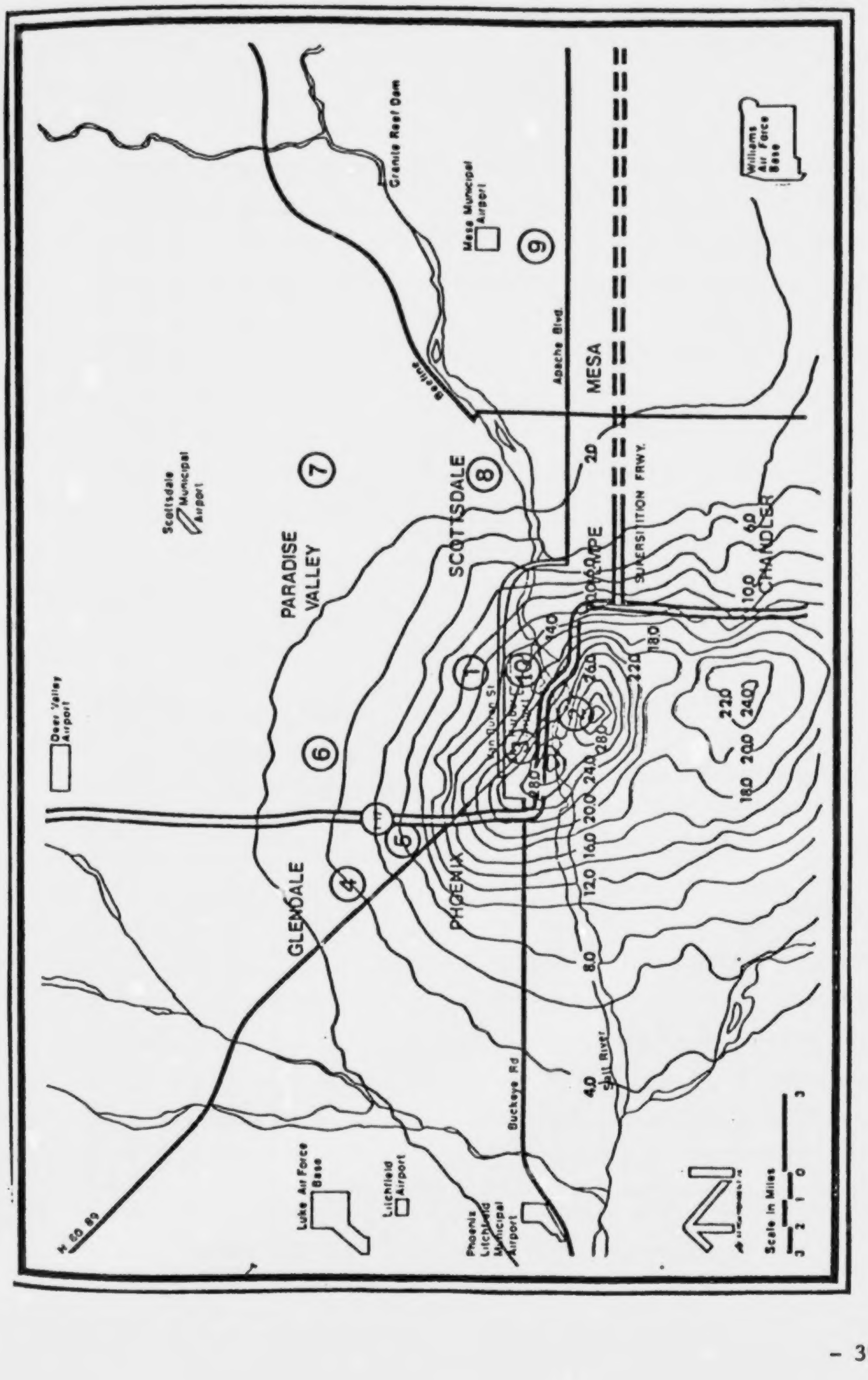
Remember how well this data fits this model because I will be talking about how well data fits models again later.

The next slide shows another example of date, in this case for an urban scale. This is Phoenix, Arizona. The highest concentrations, for carbon monoxide for an eight-hour period, are about 30 milligrams per cubic meter. The same sort of conversion formula I gave earlier applies that for the kind of 1985 vehicle mixes we are talking about. This, therefore, would mean that there would be a particulate matter concentration under these circumstances, which is a worst case type of situation in Phoenix, of about 30 micrograms per cubic meter which is a substantial particulate matter impact in relationship to the national ambient air quality standards for particulate matter. #7

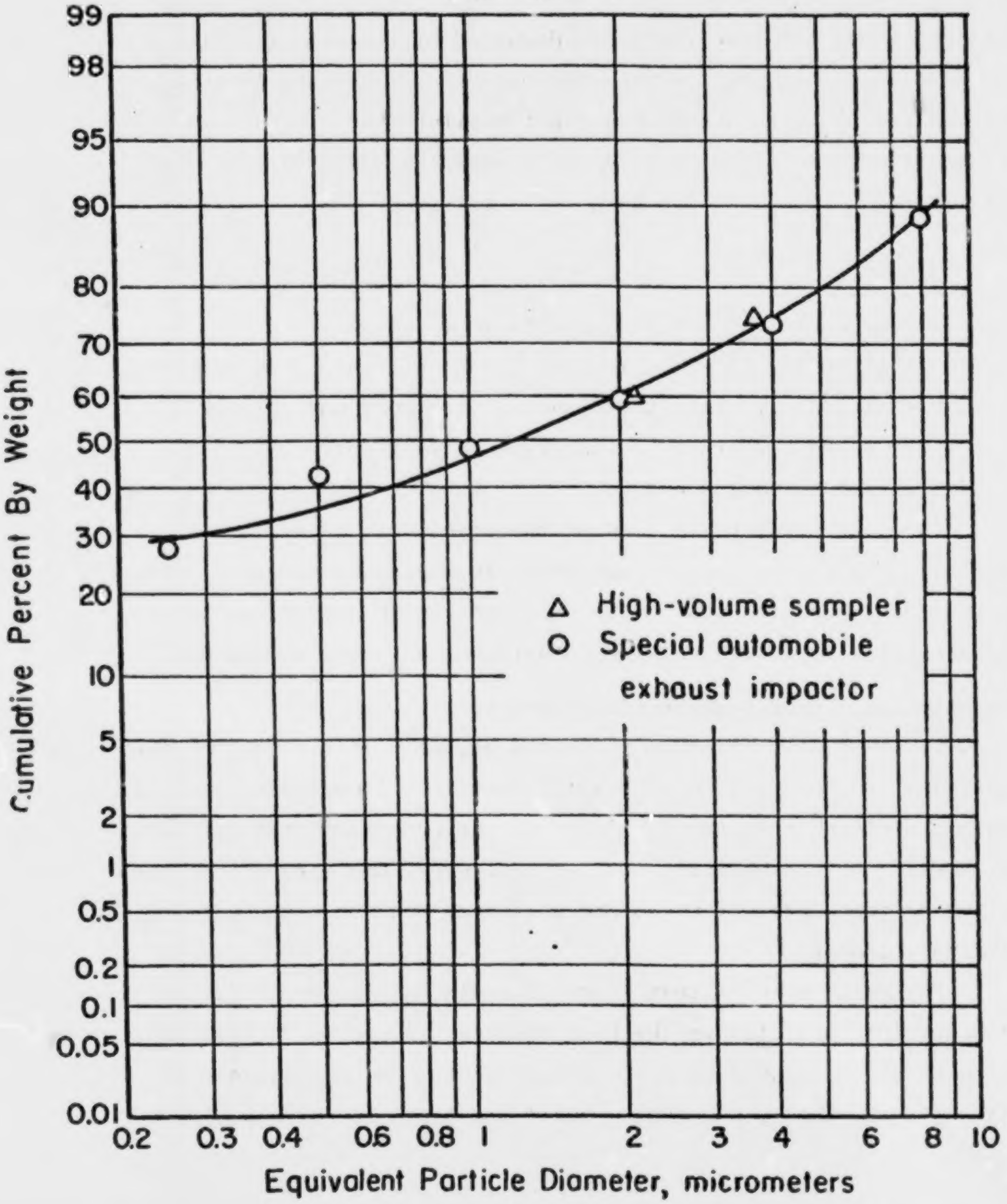
There is another aspect to the regional or mesoscale considerations here, and that is that the particles that are emitted from diesel exhaust, both because of their size and because of the high sulfate content, have a strong effect on scattering of light, which has a visibility effect that has to also be considered.

So far we have treated the modeling of dispersion in a very simplified manner. Now, in real life, life gets more complicated.

The next slide introduces the first of the complications. #8
The first complication is that particulate matter is not all small. It doesn't all behave like gases, and actually there is a distribution of sizes. During the Los Angeles catalyst study, in which sulfate emissions were studied alongside actual roadways over the



Isopleths of predicted 8-hour CO concentrations in ppm for the 1975 case. The locations of the monitoring sites are shown.



Particle size distribution of upwind pollutants at San Diego Freeway site.

last couple of years, size distributions of particulate matter were measured. These are size distributions upwind of the freeway. Thirty percent of the particulate matter weight is down below .2 micron, and about 50 percent is below 1 micron. This is ambient air, sort of a mixture in this case of marine and other aerosols.

Now, the next slide which should be superimposed on top of this one shows the same situation downwind of the same roadway. #9

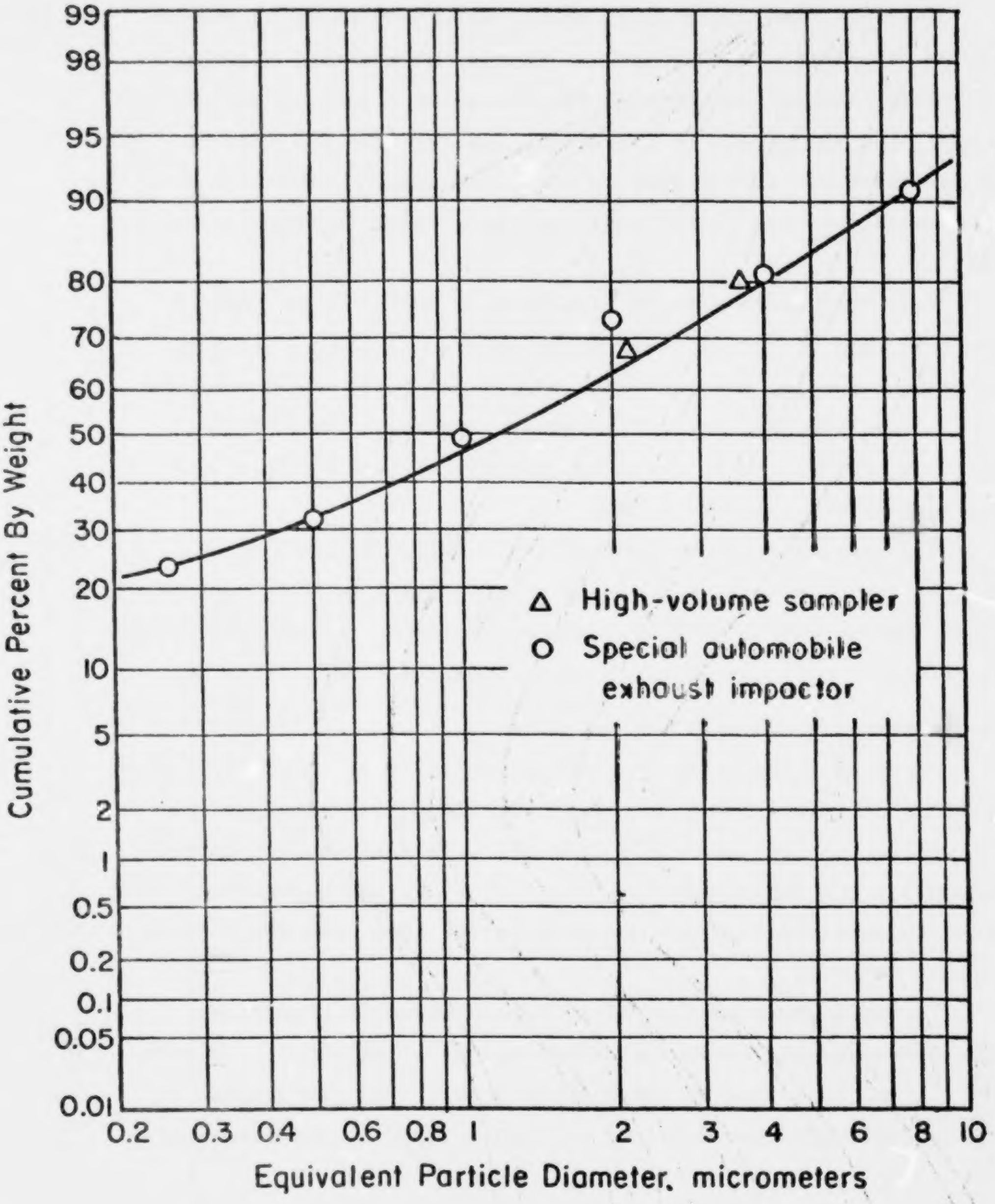
Okay, now if you remember the one we were looking at before started with 30 percent of the weight smaller than 0.2 microns. The new one starts at 20 and goes up more steeply, and indicates that the major added mass was in the large particle range for the traffic in 1975.

Now, this seems sort of misleading. Sulfates are small particles, and the other particle emissions are small, but what really is happening are that most of the particles are re-emitted. It is re-emitted dirt from the roadway, tire wear and things of that sort, so that there is an increase in small particles, too, but the distribution changes nature.

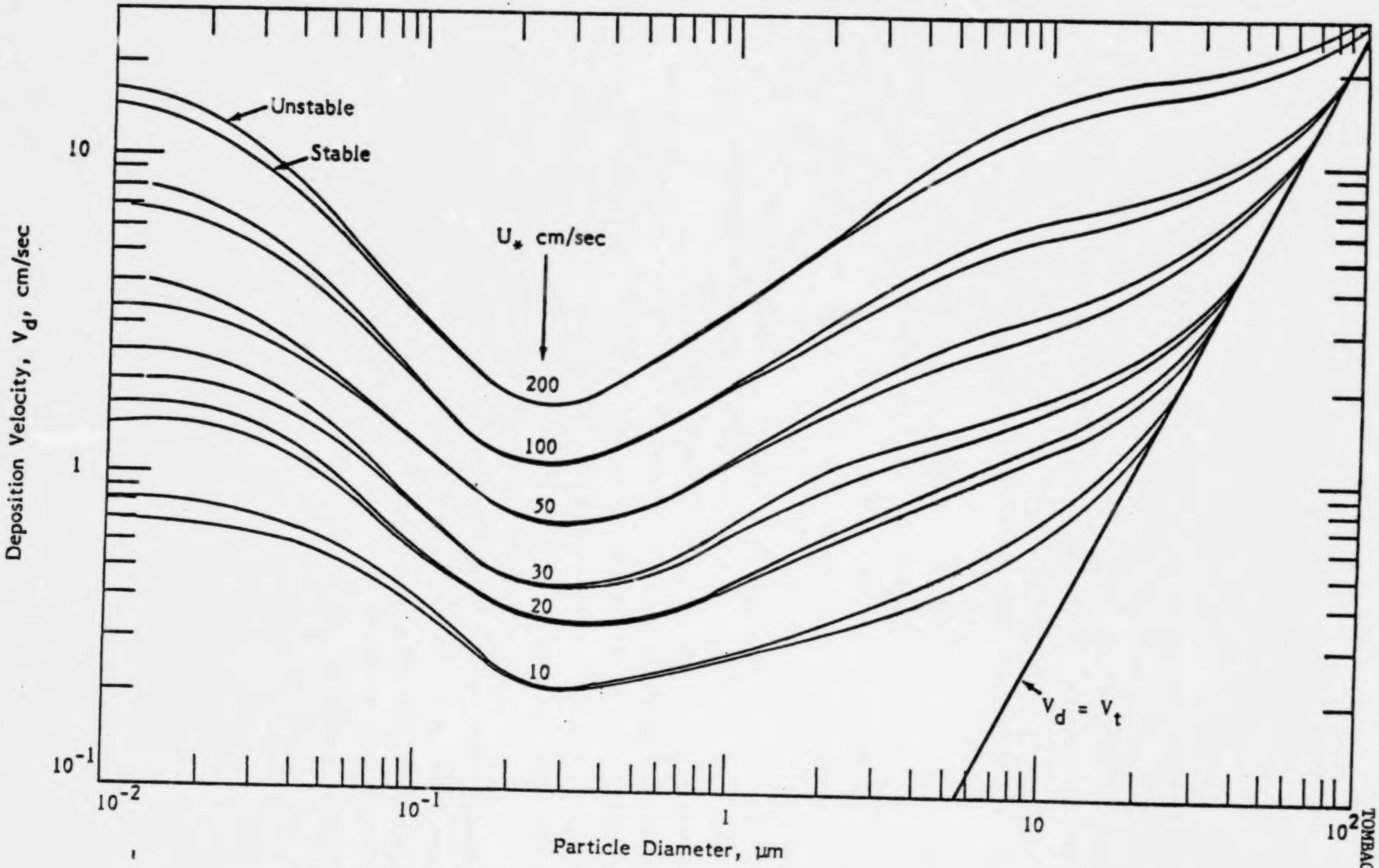
The next slide shows some of the physics involved in small particle dynamics. In this case there is a plot of particle diameters versus the deposition rate of these particles in a real atmosphere. The parameter U_* is an index of turbulence, with increasing U_* representing a more turbulent atmosphere. #10

First of all, V_t is the terminal velocity of the fall of the particles if they fell in a totally turbulence free stmosphere. In real situations the rate of fall is not as great. As the particles get smaller the atmospheric motions take over, and also affect the motion so that the fall rates are different than they would be at terminal velocity.

The point here is that there is a minimum in deposition velocity for particles in the size range of .1 micron to 1 micron, which is the area that we are talking about. The consequence of that is that, when you consider residence times in the atmosphere



Particle size distribution of downwind pollutants at San Diego Freeway site.



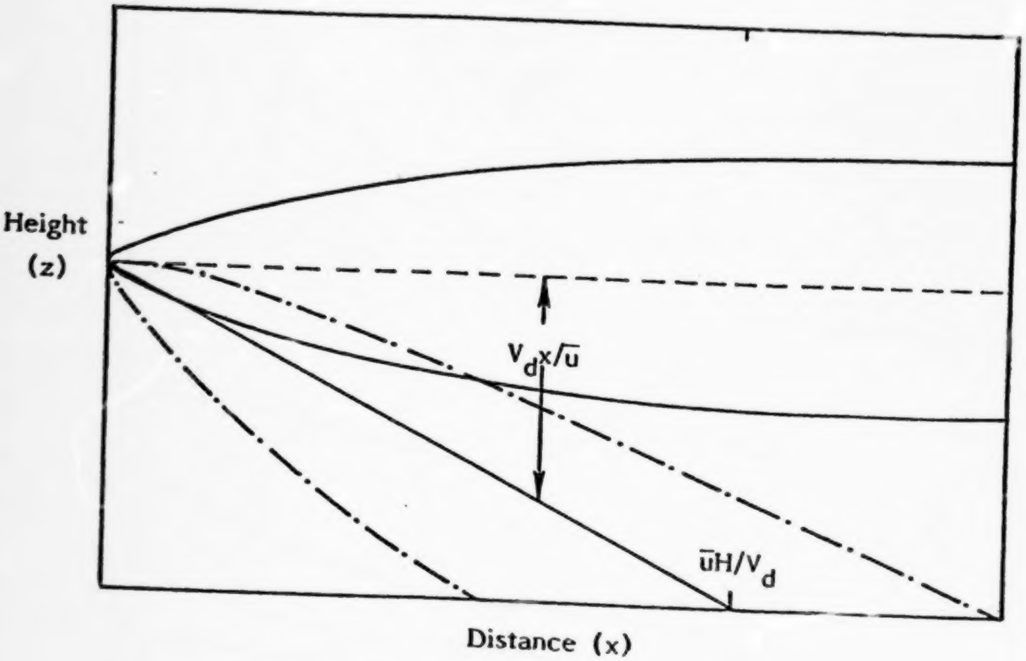
Predicted deposition velocities at 1 meter height for particle density of 1 g/cm^3 and surface roughness Z_o = 3.0 cm. U_* is the friction velocity. (From Sehmel and Hodgson, 1974.)

for particles, .1 micron particles reside in an atmosphere, considering urban type mixing conditions, for times of the order of thousands of hours. Ten micron particles reside in the atmosphere for times on the order of tens of hours and there is sort of a linear difference in between. These times will become of significance when some of the chemistry is discussed a little later.

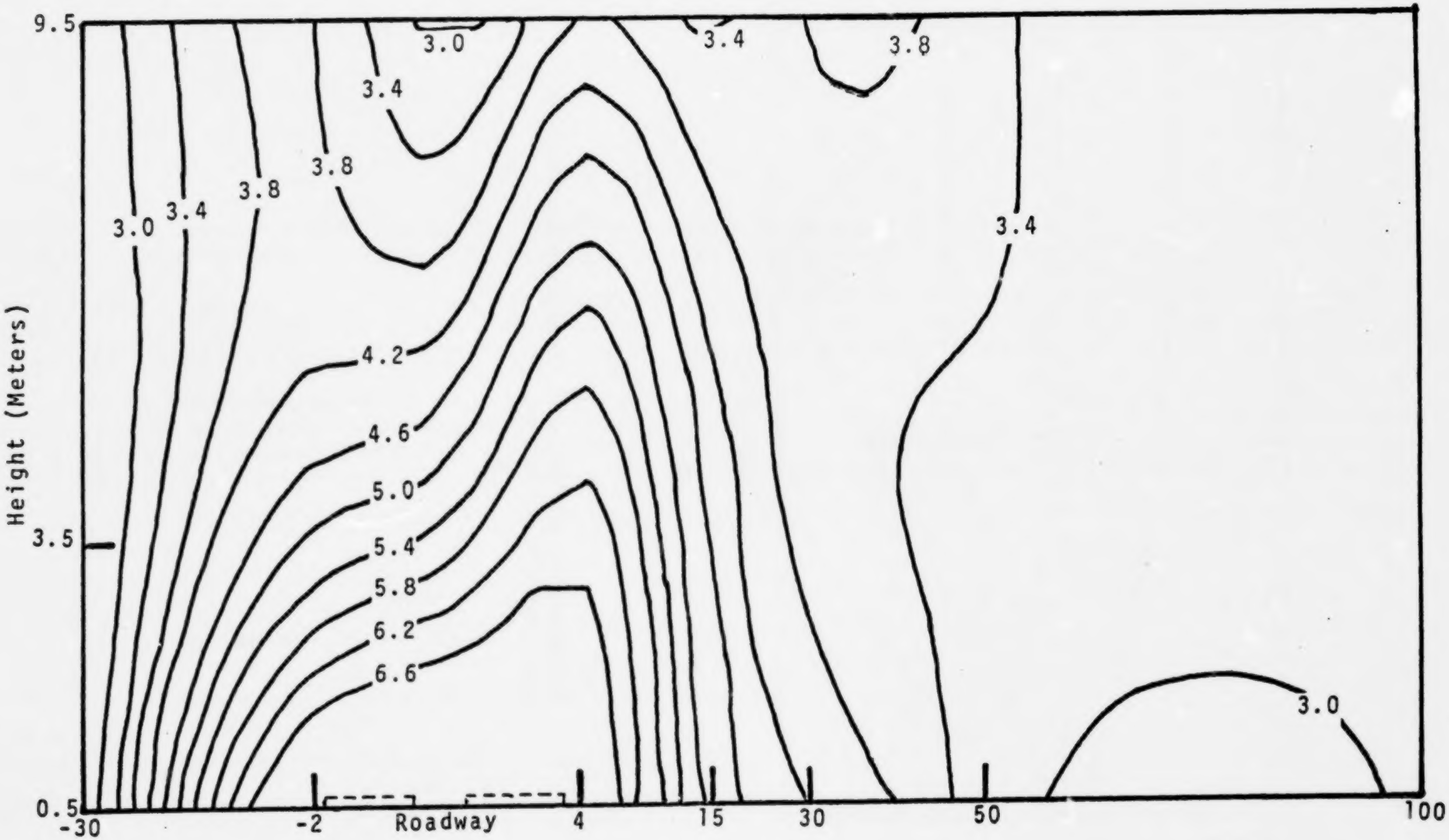
The next slide shows a concept for modeling of particulate #11
matter where all one does is tilt the wind vector so it heads toward
the ground at the speed shown in the previous slide, with the aerosol
distribution is broken up into different size increments, and the
ground is assumed to be an absorbing surface. So, instead of the
plume going horizontally it descends downward. That is a mechanical
tool.

Now, going on to some more data, General Motors several years
ago ran a grand experiment studying sulfates from vehicles where
several hundred vehicles ran around a test track for a long period
of time and the sulfate concentrations were measured both vertically
and horizontally from the roadway. This slide is just an example of the #12
kind of data. The roadway goes into the paper. If one takes this
data and plots it on some of the earlier curves I showed you you will
find out that the decay curves are of the same kind.

The next slide discusses some information that was deduced from #13
the Los Angeles catalyst experiemnt for sulfates, and this is directly
extendable to the diesel particulate case. The most important point
here is that there are various types of categories of people being
exposed to particulate matter: automobile passengers, pedestrians
near highway, pedestrians in urban streets, nearby homes and homes
about five blocks away from expressways. Considering the worst kind
of meteorological conditions you can imagine and assuming that you
have got 25 percent of the vehicles emitting .05 grams of sulfate,
50 milligrams of sulfuric acid or sulfate per mile, you end up with
numbers in micrograms per cubic meter like those in the last column.



Schematic representation of tilted plume treatment of heavy particles at velocity V_d.



Total Sulfate ($\mu g/m^3$) Contour Plot for Run 3020804.

PREDICTED SHORT-TERM INCREMENTAL EXPOSURES TO SUSPENDED PARTICULATE SULFATES AND SULFURIC ACID EMITTED FROM VEHICLES EQUIPPED WITH OXIDATION CATALYSTS*

			Incremental Exposure (micrograms per cubic meter)			
			Normal Meteorology		Worst Meteorology	
Human Exposure	Highway Source	Method of Estimation	Wind Directly Across Highway	Wind at Worst Angle	Wind Directly Across Highway	Wind at Worst Angle
Automobile Passengers	Expressway	Dispersion Model	2			
		Lead Surrogate***	4 to 5	7	22	124
Pedestrians	Near Expressway	Dispersion Model	2			
		Lead Surrogate***	3 to 7	5	20	88
Pedestrians	Urban Street** Canyon	Dispersion Model	4 to 6			
		Lead Surrogate***	2 to 9	-	--	--
Nearby Homes	Expressway	Dispersion Model	1	2	19	33
Homes About 5 Blocks Away	Expressway	Dispersion Model	0.3	0.3	5	6

*Emission assumptions: 25% of vehicle miles traveled on busiest multilane expressway (20,000 vehicles per hour at 30 mph by vehicles) equipped with oxidizing catalysts emitting .05 grams of sulfuric acid or sulfate per vehicle mile: Ohter 75% of vehicle miles involve no emissions of sulfuric acid and suspended sulfate. Peak hourly values are tabled.

**Assumes 10,000 vehicles per hour instead of 20,000. Actual observed carbon monoxide values in medium sized suburban shopping center indicate that peak hourly exposures to 4.5 to 5.3 $\mu g/m^3$ of carbon monoxide and by inference 1 to 2 μg/suspended sulfates and acid aerosols would occur.

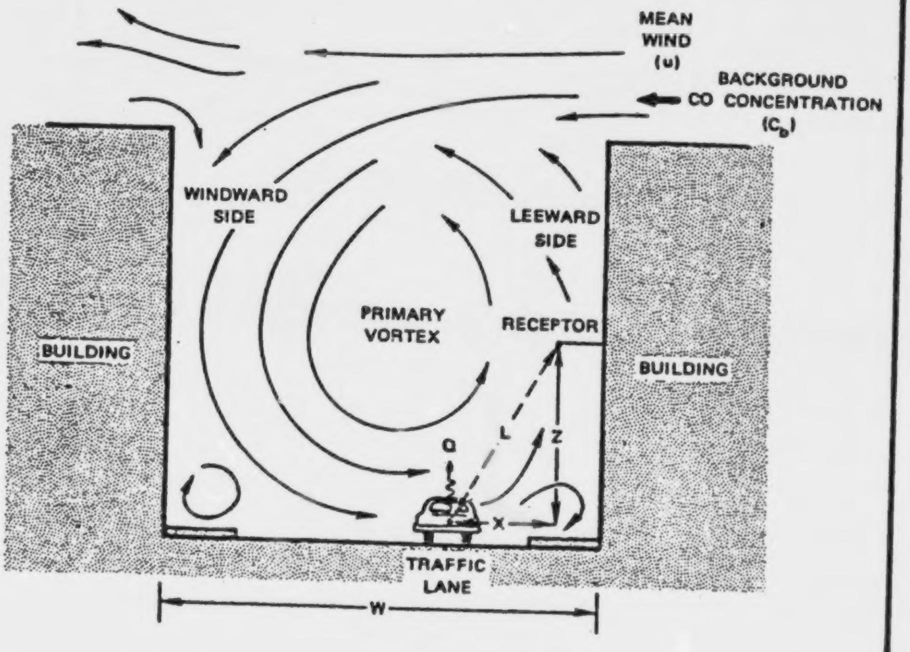
***Computed by multiplying observed lead levels by adjustments for differences in emissions per vehicle mile and percentage of vehicle miles emitting the particulate of interest: (observed lead level) X (.25) or .18 times observed.

Now, if you will recall when we were talking yesterday, for diesel particulates instead of 50 milligrams we were talking about 500 milligrams of particulate matter per mile and also we are talking about like 25 percent of the vehicles sold in 1986 being diesels. So, if the numbers in this table are miltiplied by 10 that gives you the expected particulate matter concentration in and around roadways. It says that, assuming there are no filtering systems in cars, windows are open, you would havelike 1000 micrograms per cubic meter inside vehicles, 800 next to it and so forth going on down.

You can, also, multiply any of the other numbers by 10 to get the total particulate matter impact of a 25 percent diesel mix. You can also do this for BaP. The numbers that were being bandied about yesterday were on the order of 5 micrograms of BaP per mile. So, if the numbers in the table are divided by 10 and treated as nanograms per cubic meter you get some idea of the BaP concentration. So, you are talking about like 100 nanograms per cubic meters inside the vehicle and 100 near the roadway and going on down from there.

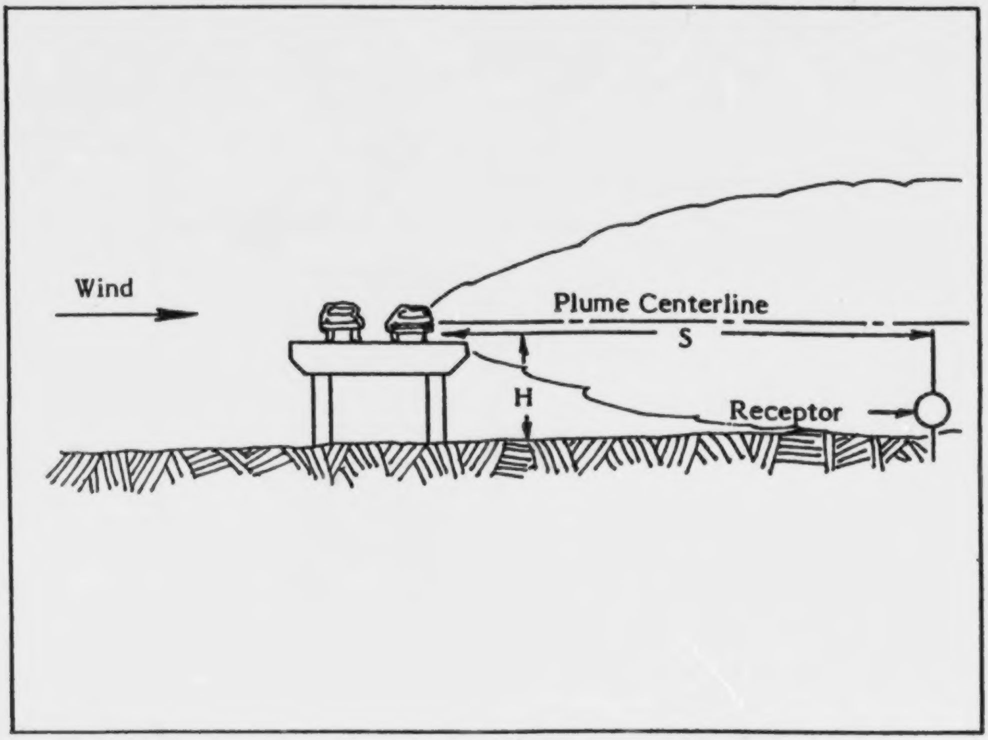
Another complication besides the fact that there are real particles starts on the next slide, and that is that there are #14 terrain obstructions to mixing of pollutants. One of the more serious ones in urban areas is the fact that there are buildings in the area, and the air flow gets quite different in this case. You will have a wind that is going one way, with a recirculating eddy, and the highest concentrations are on the upwind side of the street. There have been studies done that show the stores on upwind sides of streets have very high carbon monoxide concentrations inside them, at least the ones that were built back in the old days before you had roof mounted ventilating systems.

There are other aspects to the terrain effect which are shown #15 in some of the next slides. One is that elevated roadways on viaducts have a different kind of an impact pattern. The plume does not impact near the roadway at all. It has a good deal of time to disperse before the first receptor on the ground feels it.



SCHEMATIC OF CROSS-STREET CIRCULATION BETWEEN BUILDINGS

Source: User's Manual for APRAC-1A Urban Diffusion Model, September 1972



Plume for elevated line source.

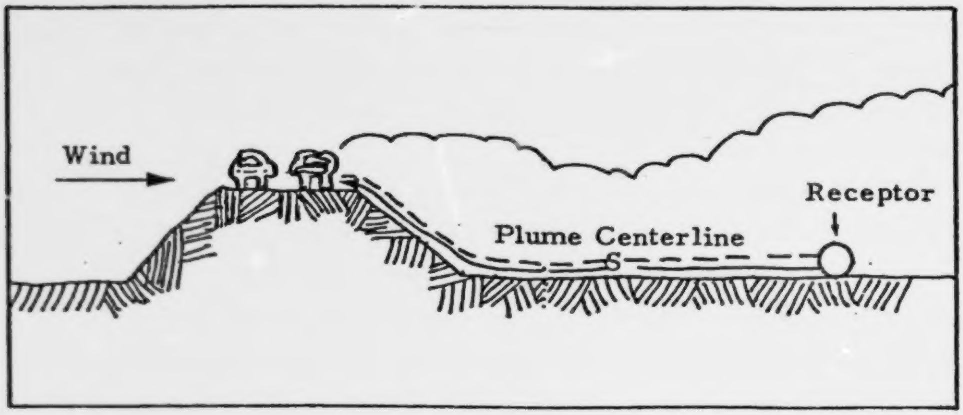
Going on to the next slide,elevated roadways which are on berms or fill have a slightly different characteristic. If the slopes are fairly gentle there is really no difference from the case where the roadway was on level terrain, but if the slopes are not gentle, and there are retaining walls on both sides, then there is a recirculating cell of air. It is much like the case with the street canyon I showed earlier. #16

The next slide shows what happens with roadways in cuts. In cuts with gentle sides things aren't very much different than on flat terrain, but with sharp cuts the plume fills up the cell. Concentrations can get fairly high, and then it disperses out, but it has had time to dilute over the cut volume. So, the dispersion is a little more rapid. #17

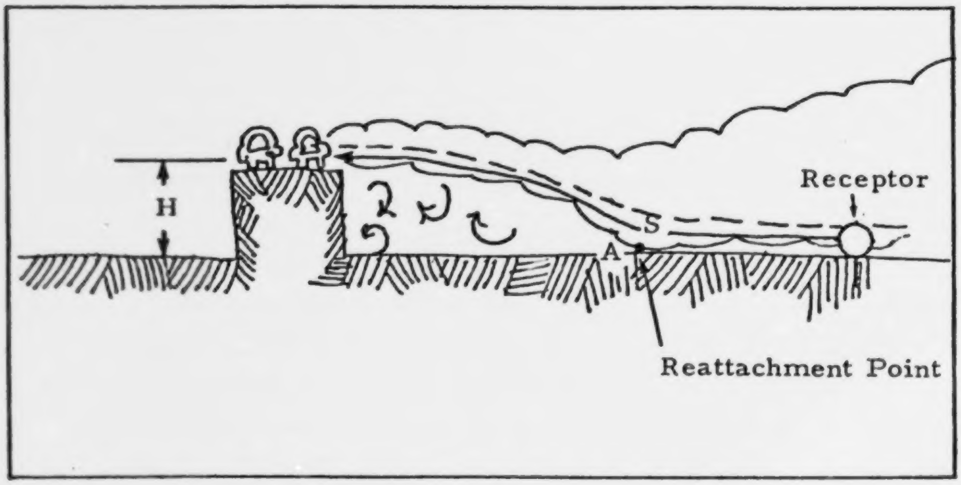
All of these are compiled into one plot in the next slide which shows distance from the roadway versus concentration, and basically says that at roadway edge, all the configurations except for the viaduct, the sharp edge cut and the sharp edged fill have the same effect. Far away they look just the same which you would expect, but they have different characteristics right near the roadway for these specific cases. #18

The chemical processes are a challenge for modeling, and even something relatively simple as photochemistry, which is child's play by comparison to some of the organic reactions, has really not been modeled very well so far.

A number of models have been developed for this purpose; I am showing a concept of one in the next slide, a photochemical reactive model in which a parcel of air with several height layers is followed, and the chemistry is carried along as a function of time in the box as well as a function of solar radiation, emissions into the box and dispersion into adjacent cells. Similar processes can be applied to organics, but one has to know reaction rates and the chemical processes involved which I don't think is where we are at the moment. #19

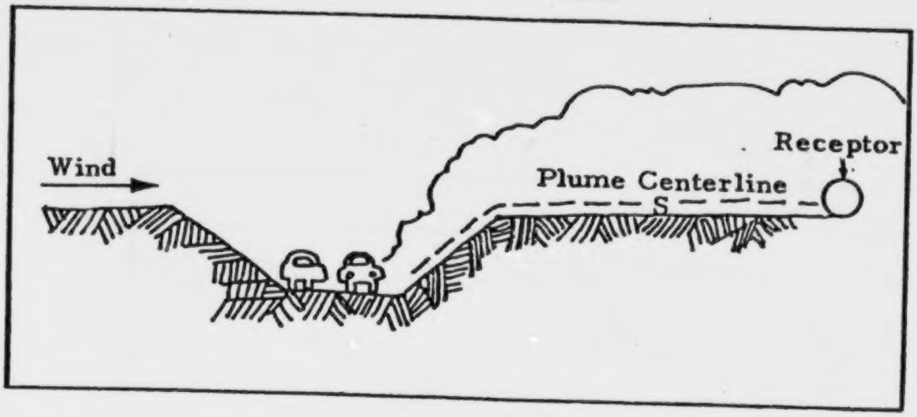


Attached Flow

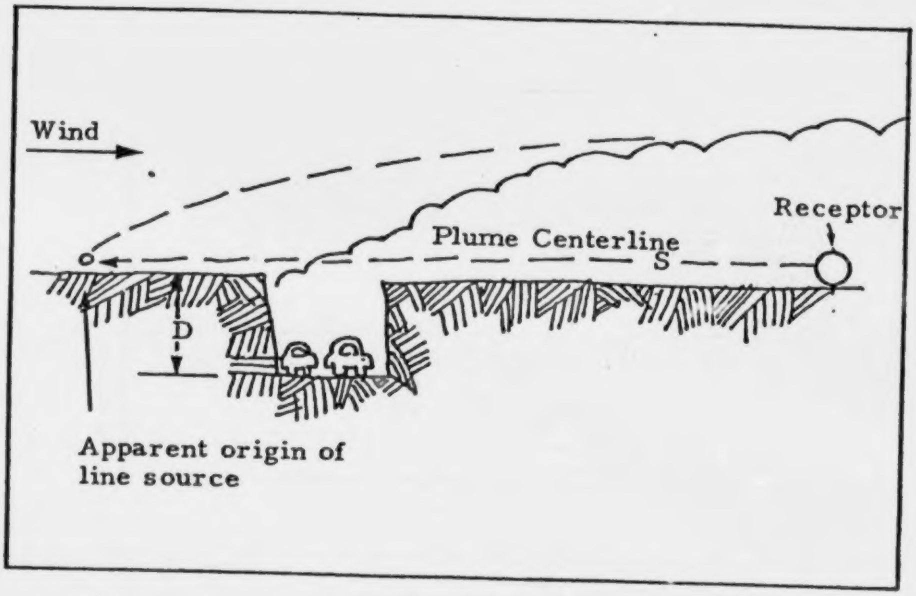


Separated Flow

Plume for source on elevated surface.

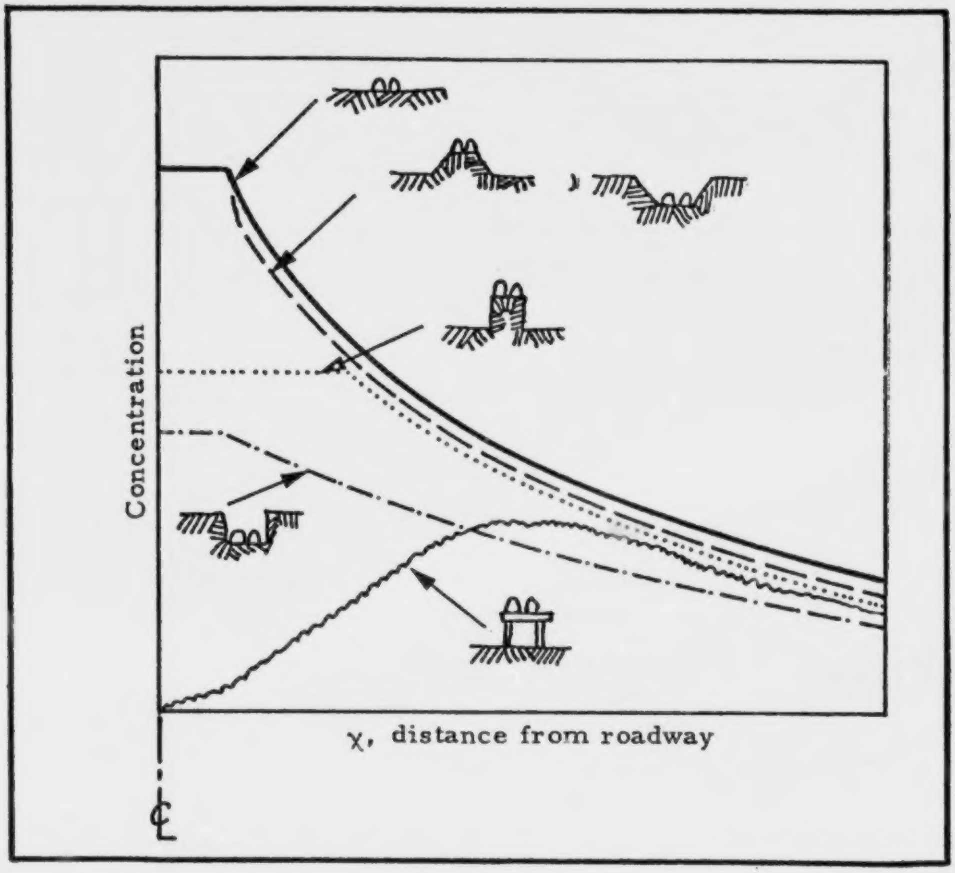


Attached Flow

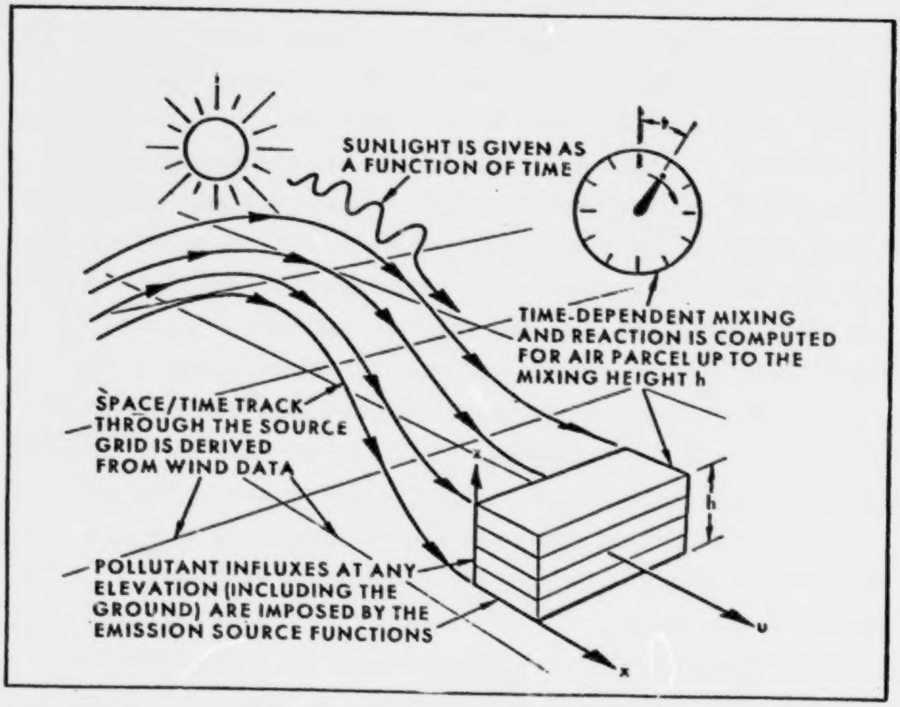


Separated Flow

Plume for source on depressed surface.



Surface concentrations for different roadways.


SUNLIGHT IS GIVEN AS A FUNCTION OF TIME
TIME-DEPENDENT MIXING AND REACTION IS COMPUTED FOR AIR PARCEL UP TO THE MIXING HEIGHT h
SPACE/TIME TRACK THROUGH THE SOURCE GRID IS DERIVED FROM WIND DATA
POLLUTANT INFLUXES AT ANY ELEVATION (INCLUDING THE GROUND) ARE IMPOSED BY THE EMISSION SOURCE FUNCTIONS
z
h
u
x

Schematic of the DIFKIN model for simulating photochemical air pollution.

Moving on to the question how good are all these models, I will give a couple of examples. This is a comparison of a number of models against some field data in California. I won't describe the models. The main point is that most of the models for this particular data set follow the perfect fit curve pretty well, except for one which is sort of off all by itself. This happens to be the EPA HIWAY model, the one that the EPA has recommended be used for modeling highways. #20

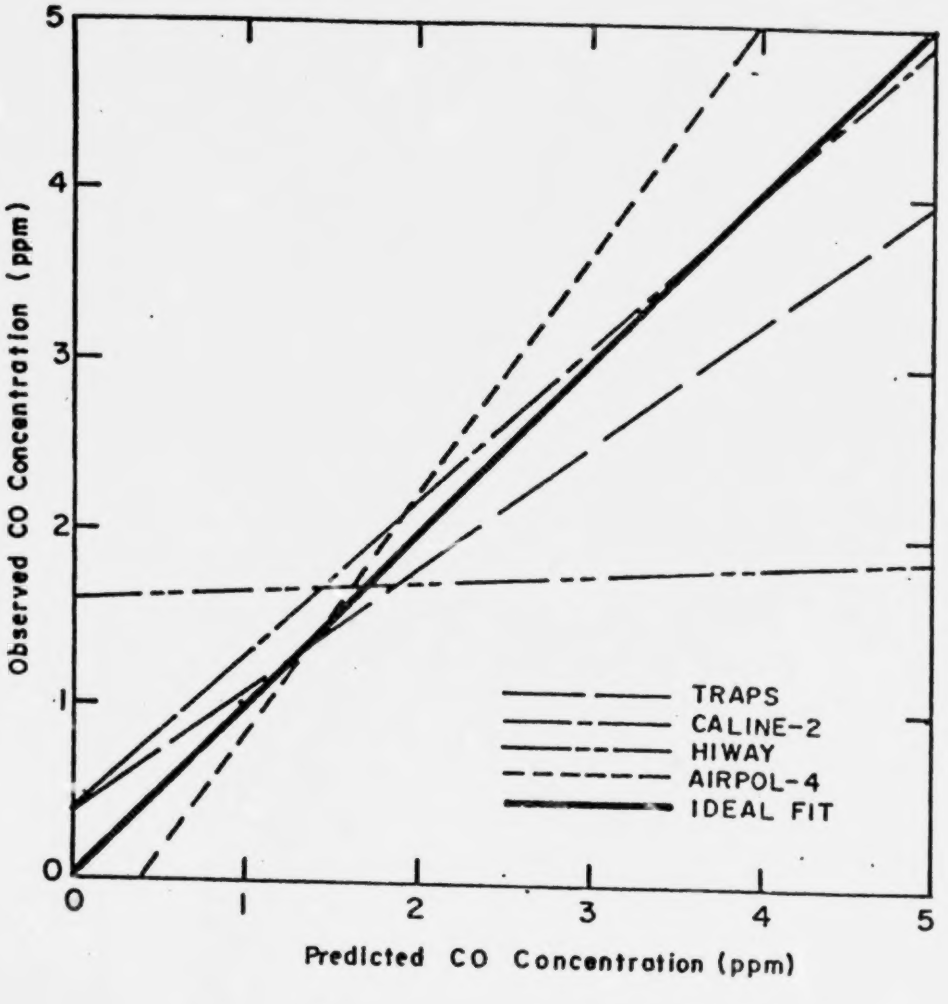
The next slide shows another comparison. This time we have distance downwind versus concentrations derived from the General Motors sulfate experiment, and the values the HIWAY model would predict under various meterological conditions. The spread of actual data over meterological conditions was much smaller than that predicted by the model which is one reason for the bad fit in the previous plot. #21

Other models predict better. So, there are various ways that you can keep track of concentrations, but basically the modeling is not too bad as long as you use the right model at the right time.

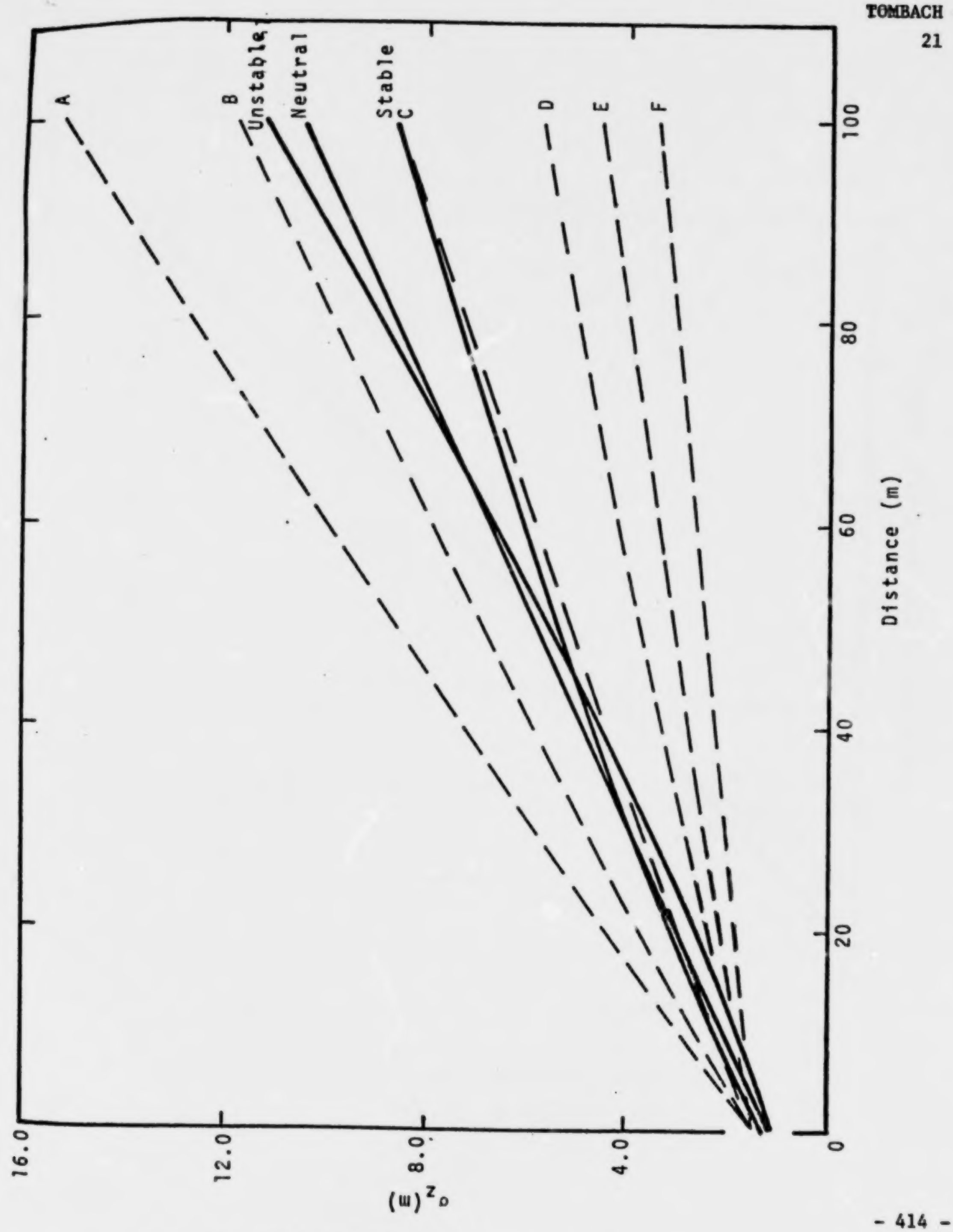
One of the questions that one asks is that are there some experimental programs that should be done with diesel particulates to look at how they disperse near roadways, and what are the concentrations and the chemical transformations. I will give three examples of studies that have been done with particulate matter in the atmosphere near roadways just to show what kind of effort is involved.

This particular drawing here is from a Stanford Research Institute dispersion study. It was on an actual freeway, going into and out of the paper or out of the board here, and there were six 50-foot towers with samplers at various heights. There were also anemometers at various heights, and there are temperature sensors also. This was a major study to study the dispersion from the roadway, the mixing by the vehicles, the plume rise because of the heated plumes and so forth. #22

The next slide shows what was done for the Los Angeles catalyst #23

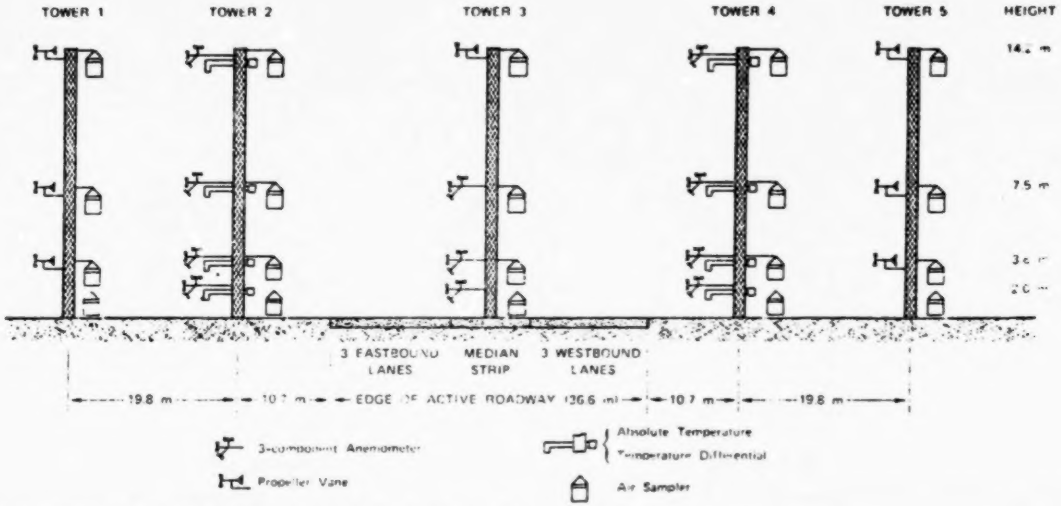


REGRESSION LINES OF MODELS FOR CALIFORNIA DATA



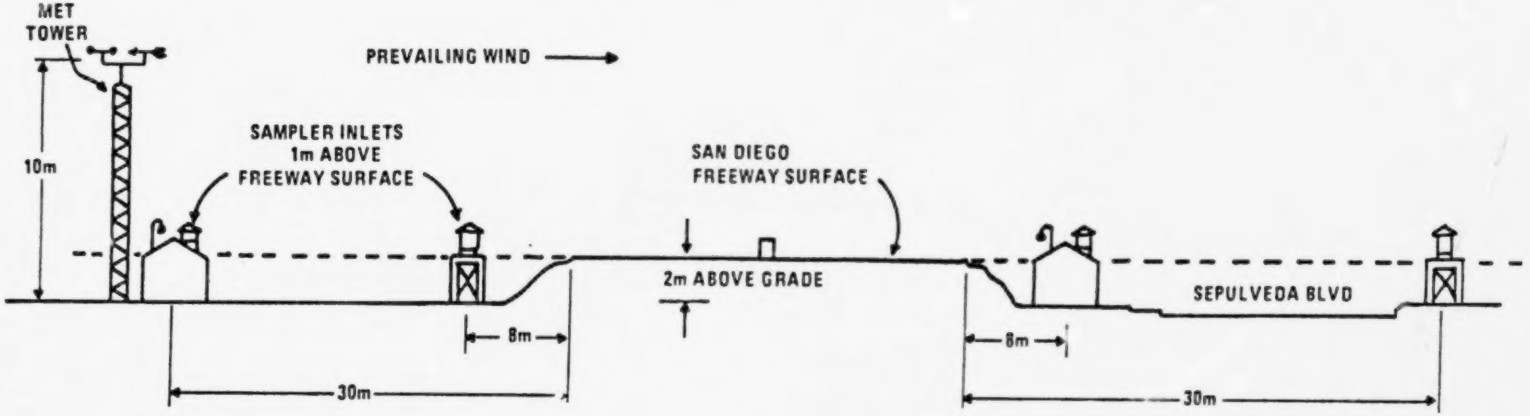
σ_z as a Function of Downwind Distance.

The Solid Lines are Estimated from the Measurements. The Dotted Lines are used by the HIWAY Model. The Stability Classes are Indicated.



NOTE Additional air samplers located at ground level on both sides of road beyond towers at 15.2 m intervals to 91.5 m from roadway edges.

AEROMETRIC INSTRUMENTATION LAYOUT



SITE A	SITE B	SITE C	SITE D
METEOROLOGICAL DATA	24-HR HI-VOL	24-HR HI-VOL	METEOROLOGICAL DATA.
24-HR HI-VOL	4-HR HI-VOL	4-HR HI-VOL	24-HR HI-VOL
4-HR HI-VOL	4-HR MEMBRANE	4-HR MEMBRANE	4-HR HI-VOL
4-HR MEMBRANE		CASCADE IMPACTOR	24-HR MEMBRANE
CASCADE IMPACTOR		24-HR SO_2 BUBBLER	
24-HR SO_2 BUBBLER		CO ANALYZER	
CO ANALYZER			
BATTELLE IMPACTOR		BATTELLE IMPACTOR	
TOTAL SULFUR ANALYZER		TOTAL SULFUR ANALYZER	
NO/NO_2 ANALYZER		NO/NO_2 ANALYZER	
O_3 ANALYZER		O_3 ANALYZER	
DICHOTOMOUS SAMPLER		DICHOTOMOUS SAMPLER	
		TRAFFIC COUNT/SPEED	

LACS study site composition and elevation.

study, again longside an actual freeway. Here the situation was a little simpler. They were only concerned with ground level concentrations. So, almost all the measurements were made near the ground. The freeway again is going in and out of the paper, there were various meterological sensors, and lots of particulate measurements, which I won't describe, at these various samplers.

Finally, a photograph of a real life situation. This is #24
the General Motors catalyst study again which had, as you will remember from the plot I showed earlier, lots of contours of data way above the roadway.

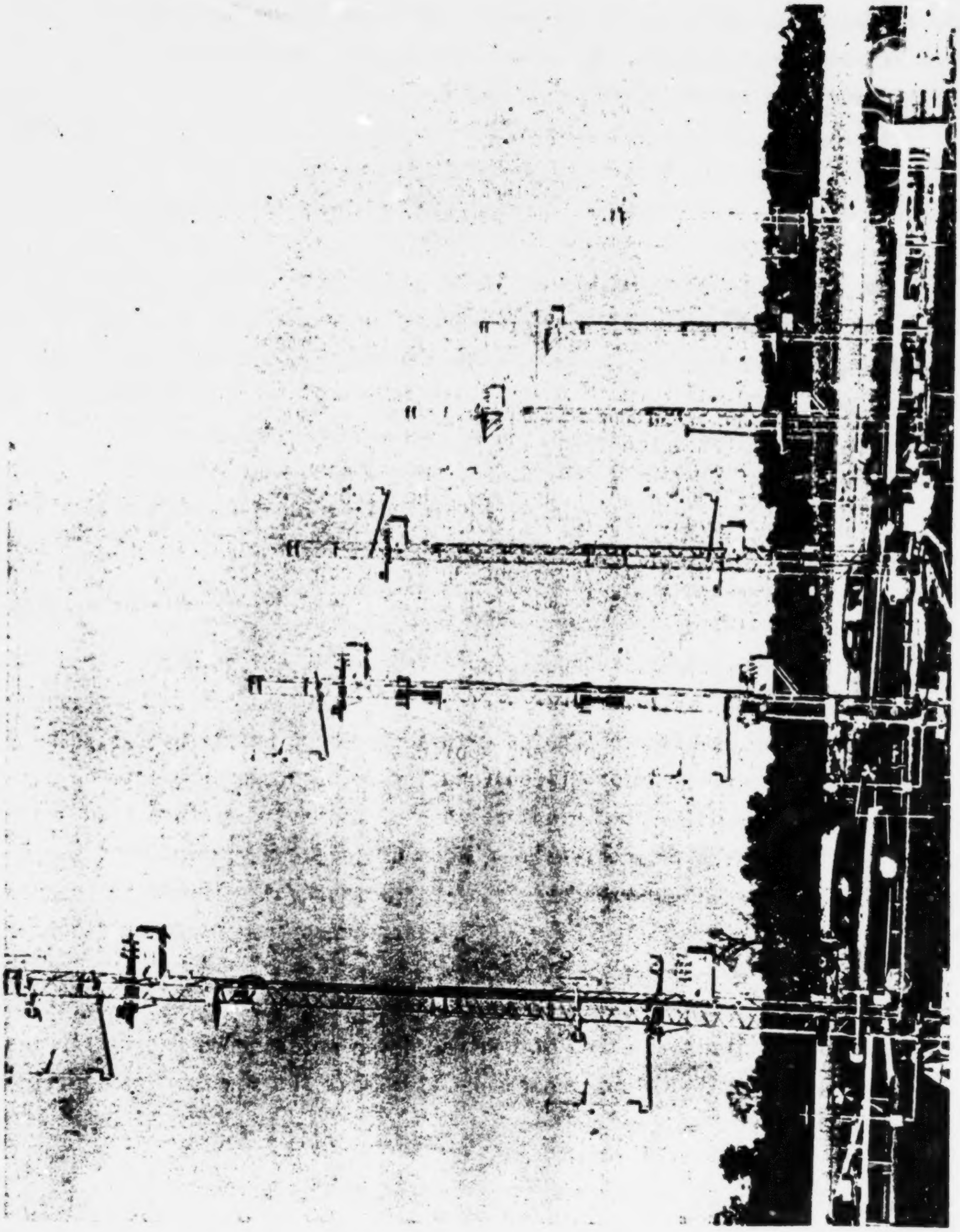
Well, the way they accomplished that was with a string of towers along across the roadway with several hundred cars racing along. The little boxes which you can barely see are all samplers for sulfates at various heights.

So, I think one can summarize this rather rapid review in a couple of short statements. One is that, relative to the other uncertainties in the diesel problem the modeling of the dispersion of pollutants near roadways is really in pretty good shape as long as one is not concerned with chemistry. Probably if all you are concerned about is dispersion no experiments are needed.

Longer scale dispersion is not always quite as good, but is also not too bad.

Now, if one goes on to chemical modeling, particularly for chemical modeling of diesel particulates, I think, you can just forget it. The data does not exist to do it. For handling that particular case, field experiements would be helpful, particularly if they covered several scales, the near roadway case, the neighborhood, as well as the area. The near roadway case means transport times of like 10 minutes and under, the neighborhood an hour and under, and the area transport of under one day. As we get into discussions later you will see that these time scales are important for understanding what is happening with the particulate matter.

Thank you for your attention.



A View of the Sampling Area During the GM Sulfate Dispersion Experiment

MR. GROBECKER: Thank you, Mr. Tombach.

I believe now is the time when you are expecting Miss Claybrook. She has not come, so perhaps we will move on to the next speaker. Oh, maybe she is here.

Before I introduce them, can I make an announcement?

(Administrative announcement.)

MR. GROBECKER: Now, we will make a break in the talks and introduce Joan Claybrook, Administrator of NHTSA and Dave Hawkins of EPA. Perhaps you would like to make some remarks?

MISS CLAYBROOK: Good morning. I want to thank all of you for joining our staff and EPA's and the Department of Energy staff in coming to this workshop. We feel it is a very important step in the consideration of diesel engines pro and con, and I especially want to thank those of you who have prepared discussions and the moderators of the four sessions, Messrs. Johnson, Hurn, Grobecker and Milby.

This Workshop which we are cosponsoring with these other agencies is intended to provide a forum for discussion of the current status and knowledge of unregulated emissions of diesel engines, what they are and how to measure them, how to control them and what effects they have on human health.

Dave Hawkins and I thought that it would be important for you if we stopped by very briefly just to tell you what our own posture and views are on this issue because it is obviously one that is going to be quite dominant in the next several years.

The first point is that we recognize that there are significant energy savings that are potentially available from greatly expanded use of diesel engines in light duty vehicles. I believe you heard yesterday that the estimated daily fuel savings by the year 2000 ranged from something 300,000 to 900,000 barrels per day, depending on the extent of the diesel usage.

The second point is that we have now been alerted to the

po

possibility of adverse effects on human health from diesel emissions that are now unregulated, namely, the particulate emissions. Positive findings of mutagenicity in the Ames salmonella test possibly could be followed by findings of carcinogenicity in the more elaborate health effects studies, and these are being done now by EPA and Dave will comment very briefly on that.

Third, the industrial capacity to produce diesel engines for light duty vehicles apparently is steadily being increased. Our understanding is such that within the next few years they could be in significant fraction of the new cars and light trucks. Twenty-five percent by 1985 seems a reasonable figure. It is one that General Motors had used in some early analysis we were doing in the fuel economy proceedings last year.

There is still some time available between now and that date to get some answers to the questions about the risks to human health and to develop and apply more effective techniques for controlling particulate emissions from the diesel engines before the automotive industry makes a major commitment to produce millions of these engines, and it has been the policy of our agency to set our fuel economy standards both for passenger cars and for light trucks at levels that we do not require the use of diesel engines.

We did propose it at one point in the light truck rule making and then decided not to count it. This will remain our policy while the essential research and development on health effects in emission control is carried out, both in the private and the public sectors.

w We will continue to support efforts that are being carried out to assess the environmental impacts, and this is being done primarily by EPA, and several other agencies are assisting, to study the impacts of the use of expanded use of diesel engines in collaboration with DOE and EPA and other agencies, and to evaluate the engineering limits of production and prototype diesel engines.

We are bound by the requirements, I do want to point out, it is very important, of the National Environmental Policy Act to make a thorough assessment of the environmental impacts of any fuel economy regulations that would result from the expanded use of diesel engines.

I would like to ask Dave Hawkins who has come to join me this morning to comment on his views which are quite similar.

MR. HAWKINS: Thank you, Joan.

Joan's statement really does outline EPA's views on the subject as well. I will make only a few additional comments.

We, too, recognize the energy conservation benefits of the diesel and therefore want to avoid any unnecessary restriction on its use. It would be inappropriate for the government to vacillate on this issue for years and thereby hold up the introduction of a technology which does have energy conservation benefits if there weren't good reasons for being cautious about it.

Accordingly we think that information on diesel emission health effects needs to be developed promptly. As a result we have initiated a very high priority health effects research program that started with short-term bio-assay screening tests. It is being followed up by additional confirmatory cell and multicell mutagenic tests and short-term live animal tests. The results of these experiments will be available in June.

As a second step we have accelerated the long-term live animal inhalation test program schedule in order to try to produce meaningful results by the fall of 1979. It is our understanding that this accelerated schedule is consistent with the schedules of some of the major manufacturers, which call for decisions on additional major capital expenditures for the diesel to be made late in 1979.

You will hear from Stan Blacker of EPA later this afternoon on the status of our health effects research. I think the basic message that I would like to convey is that the attitude of EPA is that the government ought to proceed in the right order with respect to the diesel. We don't want a situation where the government one year is pushing the industry dramatically toward the diesel only two or three years later to start waving caution or red flags. If we have caution or red flags we ought to discover them now so that we do not have a push and pull back and forth on the industry.

Our principal effort at this time is to discover just what the health and environmental impact of a significant diesel penetration of the market would be. If there are problems, we want to address those problems promptly and in a fashion that gives us answers that we have confidence in.

Both John Claybrook and I appreciate the fact that you all have gathered here to discuss diesel issues. There will be additional technical meetings this spring; I hope that all of them will serve to help us jointly find answers in this very important area.

Also here today is Clarke Bullard from the Department of Energy who will make a statement on behalf of that Department.

MR. BULLARD: Good morning. I would like to give you some indication of the way we see the problem now and what we are doing to move forward in the area.

We recognize that significant energy conservation gains remain to be achieved in the transportation sector, but we don't expect total gasoline consumption to turn downward until the early eighties, if we are lucky. We are concerned, too, that the actual on-road fuel economy performance reported is not as high as we had hoped it would be.

We think it is necessary, absolutely essential, that substantial increases in real on-road miles per gallon be achieved as soon as possible to significantly reduce the auto fuel consumption. The reduction will be necessary because the recent studies are pointing to a serious liquid fuels shortage in the mid to late 1980's.

The diesel engine is one of the most important hopes for substantial improvements in auto fuel economy for the 1980's. Certainly there are other fuel economy improvements to be obtained by future reductions in vehicle weight or improvements in engine and drive line efficiency, but we are not particularly optimistic about some of these factors as we see the increasing market share of light trucks and vans working against the increase in auto efficiency in each particular model category.

We cannot afford to wait. The design and production lead times are very long, and the vehicles produced during the next few years are going to be with us through the 1980's when we really expect the liquid fuel problems to become much more severe than they are now.

The problem will probably be translated from one of vulnerability to import interruptions to one of overall liquid fuel scarcity.

The Department of Energy certainly recognizes the possibility of negative environmental impacts resulting from the widespread use of any new technology, and diesels are no exception. We are encouraged by the fact that EPA is working to quantify the health effects of diesel emissions, and we will be closely monitoring their progress. We will also be evaluating these results in these environmental impact results in the context of other sources of similar emissions and the environmental impacts of alternatives to diesels, including for example other types of engines or the production of additional liquid fuels from synthetic fuel plants. Within this framework we shall evaluate the diesel emission impacts problem. But at the same time emission control work must proceed quickly and in parallel with the health effects work. It cannot afford to wait until after the health effects work is completed.

If significant environmental impacts are discovered, they will have to be dealt with by the control technologies under development in the next few years. It is essential that control technologies be developed by industry as quickly as possible. The Department's own control technology research program will be focused on identifying and solving some of the fundamental basic cross cutting research issues that have been identified to date.

The nation cannot afford the problems or the consequences of not using energy efficient technologies across the board. Diesels are not the only possibility in the transportation sector, but they are certainly one of the most important. We are going to do everything we can to see that the control technology moves along as fast as the EPA health effects work, so that we can make informed decisions regarding other options for dealing with achievement of energy conservation gains in the automotive sector.

Thank you.

MR. GROBECKER: I wonder if anybody from the audience would like to address questions to Miss Claybrook, Mr. Hawkins or Mr. Bullard?

MR. GIBBONS: I am Robert Gibbons of the Diesel Automobile Association. I would like to address this to all three of the government agency representatives. I would like to know how or at what stage in your thinking the problem of benzo-a-pyrene particulate and other PAH compounds in coal are affecting thinking about the overall energy situation. In other words, it is clear from many studies in London that coal fires, the use of coal, burning of coal and so forth produces an enormous amount of benzo-a-pyrene, far more than the high concentration of diesel vehicles in the City of London, for example.

The government seems from what we can see to be planning a major investment in various coal technologies from coal gasification to increased use of raw coal in various combustion systems. Now, our review of the literature indicates that scrubbers, electrostatic precipitators, other clean-up measures have been relatively ineffective in controlling these particulates, particularly benzo-a-pyrene. So, in light of that, does it really make sense to take the approach that we see taken there today or over these past two days that essentially diesel is guilty of some large-scale potential violation of the environment which to our way of thinking has not been proven at all? In fact, the evidence indicates that it is not the case. So, I would like to hear some, at least, justifications of this approach to diesel monitoring, if you will, in view of the government's massive commitment to coal technology and minor commitment to the use of coal in an environmentally safe way such as magneto hydrodynamics. That is my question.

Thank you.

MR. HAWKINS: Why don't I start off. I guess the first point I would make is we are not in favor of coal-fired automobiles.

The second point is that the purpose of the Conference or Workshop, as I see it, is not to attack the diesel or to leave the impression that the diesel is being attached but rather to assemble people to get out as many facts as we can about an issue of some concern. There have been similar workshops with respect to coal-fired powerplants.

There are some basic systemic differences that lead us to have even more immediate concerns about an automobile technology than the similar concerns which we might have about residual emissions from powerplants. The first is their location. The automobile is obiquitous in the urban environment. Automobile emissions are in immediate proximity to large numbers of people, and the automobiles are there in very large numbers.

The contrast with new coal-fired powerplants and new other energy developments such as coal gasifications is pretty great in that regard. There is much more of an opportunity for sensible stationary source siting decisions, much more of an opportunity for

for equiping those plants with control technology that we do know quite a bit about. The advances in controlling fine particulates from powerplants are significant; we still have a way to go, but important advances have been made. Also, we have some new technology, emerging technologies, which show quite a bit of promise. However the principal difference in our view is the fact that we have the opportunities to site coal-fired powerplants and other coal-fired facilities in areas of the country that are relatively isolated with respect to the urban population centers of the United States. We don't have that opportunity with the automobile.

MISS CLAYBROOK: I just want to add one minor point to what Dave said, and I think that in terms of enforcement there is that same parallel that also applies, that is that if you have ten powerplants, it is a heckuva lot easier for there to be enforcement of the control technology on ten powerplants than on 5 million vehicles or 30 million vehicles.

MR. BULLARD: Last year in the President's Energy Message he expressed his commitment for the clean use of coal and we are certainly doing everything we can to follow up on that commitment.

It is important to recognize, too, that the extent to which industries now burning liquid fuels in urban areas are going to have to switch to coal depends in large measure on the amount of conservation we achieve in other sectors relying on liquid fuels. So, we are moving forward to have powerplants switch from oil to coal and also giving incentives and holding the line on regulations that call for conservation of liquid fuels in other sectors of the economy. We are trying to proceed in a balanced way; we recognize the need for difficult tradeoffs, and we are certainly not picking on diesel fuel or diesel engines. We have this opportunity at an early date when the health effects are first being discovered to initiate actions on control technology, We believe a partnership among the various agencies of government and industry is really necessary at this early time if we are going to avoid very serious problems an and compromises that we could face in the future.

MR. GROBECKER: Any other questions?

MR. LEVINS: Philip Levins from ADL. I wonder if you could tell us, please what the future program plans are on the health effects area for comparative studies of gasoline and diesel powered vehicles?

MR. HAWKINS: I think that you will be hearing, as I mentioned from Stan Blacker of EPA this afternoon who is going to address the diesel health effects studies that we are doing. We do have some studies underway with respect to similar types of emissions from gasoline engines, and he would be glad to pursue that with you.

MR. GROBECKER: Have we another question? There is time for one more. In that event, thank you for your comments.

MISS CLAYBROOK: Thank you.

MR. GROBECKER: We then will resume the series of talks which we have before you. The next speaker is Joseph Sturm of the Departm ment of Transportation's Transportation Systems Center who will talk on the subject of Impact of Light Duty Diesel Vehicles, an Assessment Overview.

Joe Sturm.

LDV DIESEL IMPACT ASSESSMENT OVERVIEW

JOSEPH C. STURM

DOT / TRANSPORTATION SYSTEMS CENTER

PRESENTED AT DOT/NHTSA DIESEL WORKSHOP APRIL 27-28, 1978

SESSION C: FACTORS AFFECTING HUMAN EXPOSURE

WASHINGTON, DC 20590

4/21/78

LDV-1

X7504

MR. STURM: I would first like to thank the three previous speakers for placing the issues into perspective.

If I could have the first slide, please. (LDV-2)

Our real interest is the question, "What are the projected impacts over a time period of, let us say 20 years, of light duty diesel emissions?" We don't have many light duty vehicles that are dieselized at the present time. It is the potential of what may occur in the future that is of interest. In doing an assessment of what these possible impacts may be, we have to consider a variety of input information.

The first topic, which we have already heard about, is the emissions. We move on to the vehicles themselves and how these vehicles are used. That then leads into the traffic and traffic flow considerations. From there, we move on to the ambient air quality that results from whatever emissions are released. And, from that we can go on to exposure, considering both the welfare and health impacts from these results.

The next slide, please. (LDV-3)

The first consideration is the regulated emissions. We talked about these yesterday in some detail. Also, we have the unregulated emissions, which at the present time are the most controversial; these are particulates, the organics that may be associated with the particulates and odor.

One consideration that was not addressed yesterday was a change in emission factors with time. I assume with good engineering effort, that the emission factors will change; hopefully, they will decrease. The levels of emissions in 1985 or 1990 are uncertain. I don't know if anyone is willing to put forth a guess of what they may be, but this is an important consideration for any impact assessment. What should we use for emission factors for the motor vehicles that will be sold in 1985 or 1990? In addition, we have encountered the controversial issue of measuring these emissions, which was discussed in depth yesterday.

TSC

IMPACT ASSESSMENT

TOPICS

- EMISSIONS
- VEHICLES
- TRAFFIC FLOW
- AMBIENT AIR QUALITY
- EXPOSURE
- HEALTH AND WELFARE IMPACTS

4/21/78

LDV-2

X7504

TSC

IMPACT ASSESSMENT

EXHAUST EMISSIONS

- REGULATED
  CO, HC, NO_x
- UNREGULATED
  PARTICULATES, PARTICULATE/ORGANICS,
  ODOR, SULFATE, SULFURIC ACID, ETC.

EXHAUST EMISSION FACTORS

- CHANGE WITH ADVANCES IN ENGINE DESIGN
- MEASUREMENT TECHNIQUES

4/21/78

LDV-3

X7504

The next slide, please. (LDV-4)

We are talking principally at this session about the light duty vehicles, passenger cars and trucks. I have not heard anything yet about the consumer acceptability of these vehicles. It is one element that we should consider. I am not certain how to do it. It is an element that we must track into the early eighties which will affect the penetration of these vehicles into the fleet. The impacts, of course, are directly related to both the emission factors and how many vehicles you have in the fleet.

We should not forget that in the urban situation we have diesel sources other than the anticipated light duty diesel vehicles. We have the medium duty truck, partially dieselized, and heavy duty trucks that are almost entirely dieselized. We have transit buses and railroad locomotives that are dieselized. If you are on the seacoast or on a riverport, there can be vessels with diesel engines; and, of course, we have the off-road construction equipment which is highly dieselized. All of these emissions will blend into the background and must be added to whatever emissions we would project for the light duty vehicle to obtain total diesel emission loads, unless you are looking just for the incremental change.

The next slide, please. (LDV-5)

Moving on to the next topic, we have traffic flow. This is where we get our actual impacts, the generation of emissions, that are associated with vehicle use. Anyone who drives a car realizes that traffic has a wide variability in both its spatial and temporal dependency. At this point, the scale is of interest, whether you are considering micro-microscale at the street level or street canyon, or a more mesoscale approach of an air shed for an entire urban area, which the first speaker addressed today.

The greatest potential local problem sites will be the streets in the central business district. We have already heard some comments about urban freeways, street canyon situations and parking

IMPACT ASSESSMENT

THREE VEHICLE CLASSES

- LDV - AUTOS AND LIGHT TRUCKS

  CONSUMER ACCEPTANCE, PENETRATION
- MDT
- HDT

4/21/78

LDV-4

X7504

IMPACT ASSESSMENT

TRAFFIC FLOW

- SPATIAL AND TEMPORAL DEPENDANCY

POTENTIAL LOCAL PROBLEM SITES

- CBD STREETS
- URBAN FREEWAYS
- PARKING FACILITIES·

4/21/78

LDV-5

X7504

facilities from the previous speaker. These are unique sites where the diesel vehicle may have the greatest adverse impact.

I would like to go on to the next slide with my apologies if it isn't dark enough to see clearly. (LDV-5-1) The first slide is a photograph of downtown Saint Louis. I picked this site because the information was readily available from the work done by Stanford Research Institute on CO modeling in the early 70's.[1] You are looking primarily West. The picture was taken from a helicopter almost directly over the Mississippi River.

May I have the next slide, please. (LDV-5-2)

What I will be showing you are the CO profiles of street canyons. With several assumptions, one can ratio these CO profiles for diesel particulates. Assuming that the traffic volumes are the same on the streets (estimated to be less than 1000 vehicles per hour), that the vehicles are 100% dieselized, and that the particulate emission factor is 0.5 gram per mile, 1ppm CO equals 10 micrograms per cubic meter loading of diesel particulate.

May I have the next one, please. (LDV-5-3)

Shown here are the profiles for the street canyon for different wind conditions with elevation. The lines in the upper righthand corner are very close together and represent around 10 parts per million CO. If you accept my assumptions, the extrapolations to the diesel case results in about 100 micrograms per cubic meter loading of diesel particulates, clearly a case for concern.

Next slide, please. (LDV-5-4)

I think you have already seen this slide or a similar one from the GM Sulfate Experiment,[2] another readily accessible data source. The total sulfate was measured during this experiment and is shown in micrograms per cubic meter. Again, a direct ratioing

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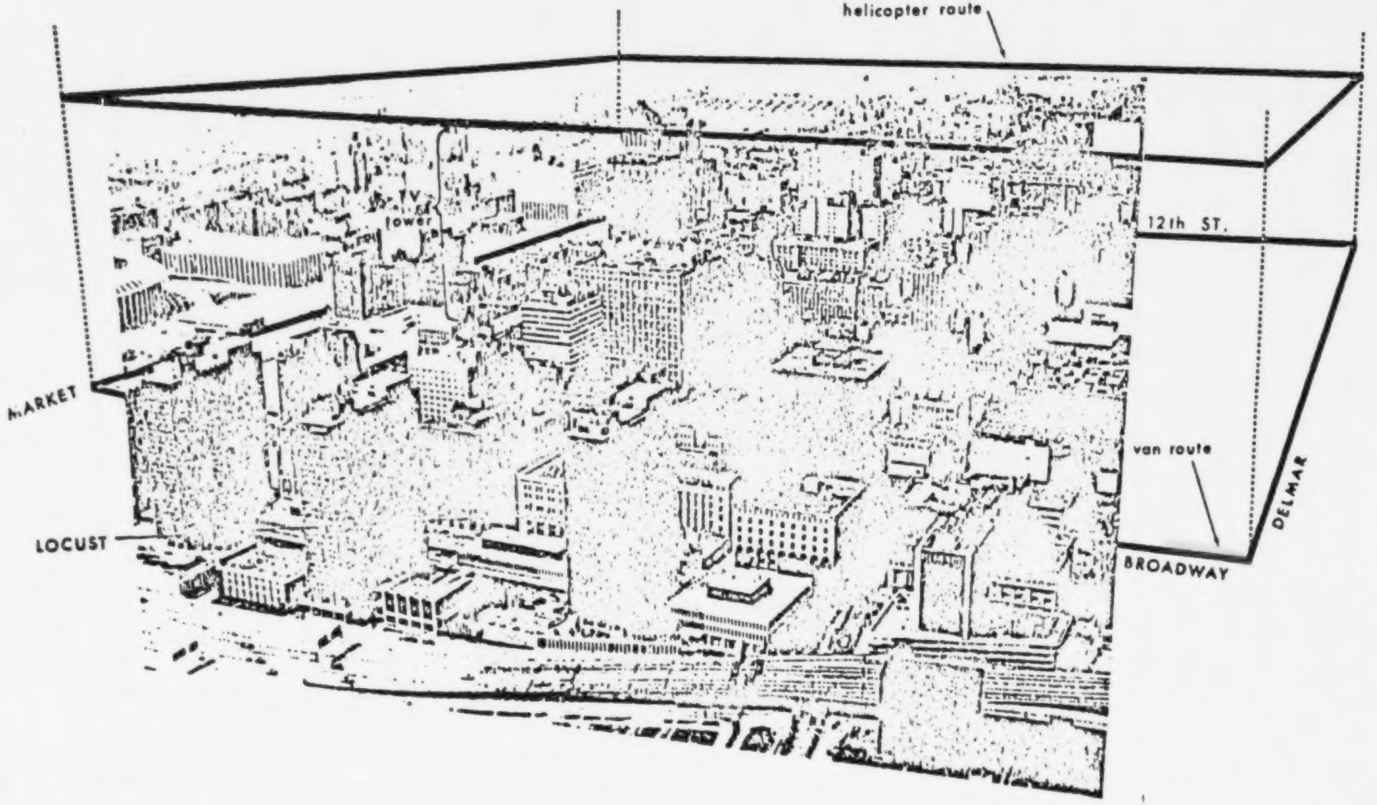
1. "Evaluation of the APRAC-1A Urban Diffusion Model for Carbon Monoxide," F. L. Ludwig and W. F. Dabberdt, Stanford Research Institute, Feb., 1972.

2. "General Motors Sulfate Dispersion Experiment: Experimental Procedures and Results," S. H. Cadle, et al, JAPCA, 27.1. Jan., 1977.

TSC

AERIAL VIEW OF ST. LOUIS CENTRAL BUSINESS DISTRICT



11/2/77

ST. LOUIS CO PROFILES

1 ppm CO $\simeq$ 10 μg/m^3 DIESEL PARTICULATE

ASSUMING DIESEL PARTICULATE BEHAVES AS CO GAS

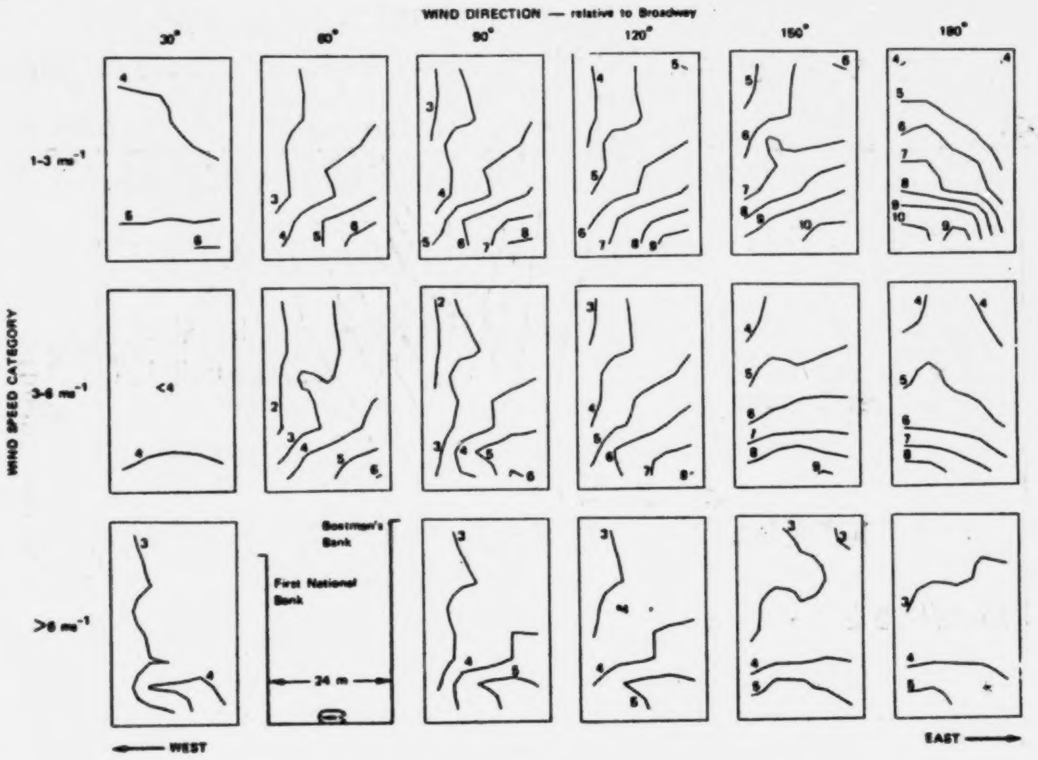
PEAK HOUR TRAFFIC VOLUMES ESTIMATED

- 500 TO 800 VEHICLES - LOCUST
- 700 TO 1000 VEHICLES - BROADWAY

11/2/77

W8561

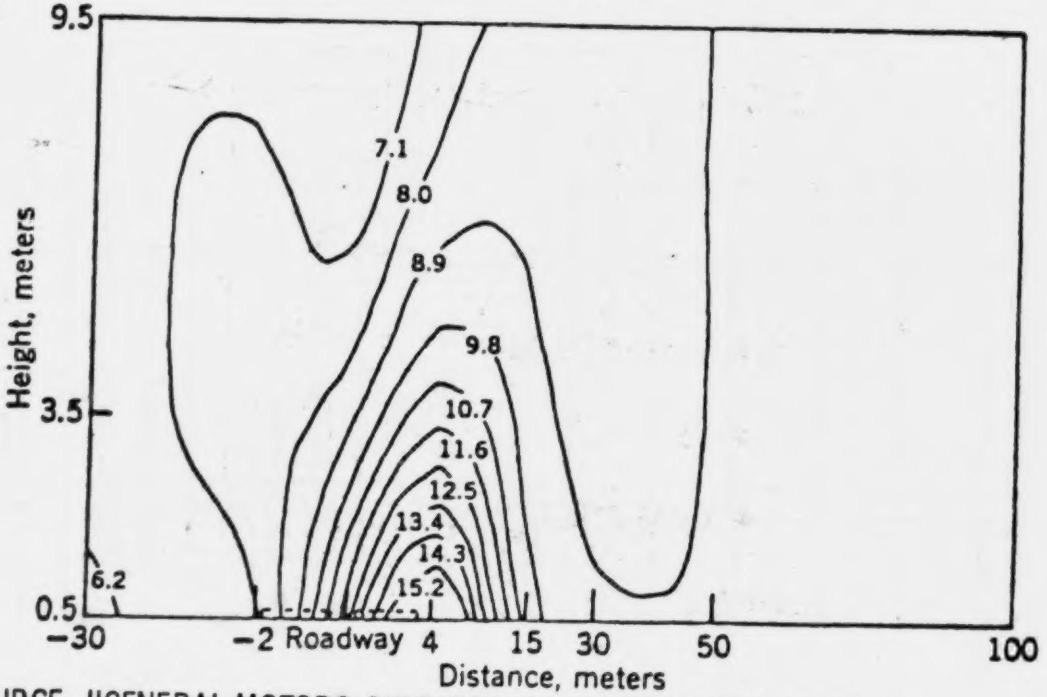
DISTRIBUTION OF CO CONCENTRATION IN BROADWAY STREET CANYON



11/2/77

W8561

TOTAL SULFATE ($\mu g/m^3$) CONTOUR PLOT
FOR RUN 2860845



SOURCE: "GENERAL MOTORS SULFATE DISPERSION EXPERIMENT:
EXPERIMENTAL PROCEDURES AND RESULTS"
STEVEN H. CADLE et al., JAPCA 27:1, pp. 33-38

to diesel particulate is possible by assuming it behaves as the sulfate particle, 100% of vehicles are diesel powered, and the diesel particulate emissions factor is 0.5 gram per mile.

On the next slide (LDV-5-5), you see a scale factor of around 13 to 1. The loadings increase to over 200 micrograms per cubic meter, immediately over the roadway. Now, the question again, is would we ever have a situation where the diesel particulate emission factor is 0.5 gram per mile and a vehicle volume is something over 5000 diesel vehicles per hour?

Next slide, please. (LDV-6)

In the projection of ambient air quality, we have already heard about the air quality models that are available. These models require input information. These models require fleet mix, emission factors, traffic variables, various site descriptors, the meteorological values, and then, out pop the ambient air concentrations.

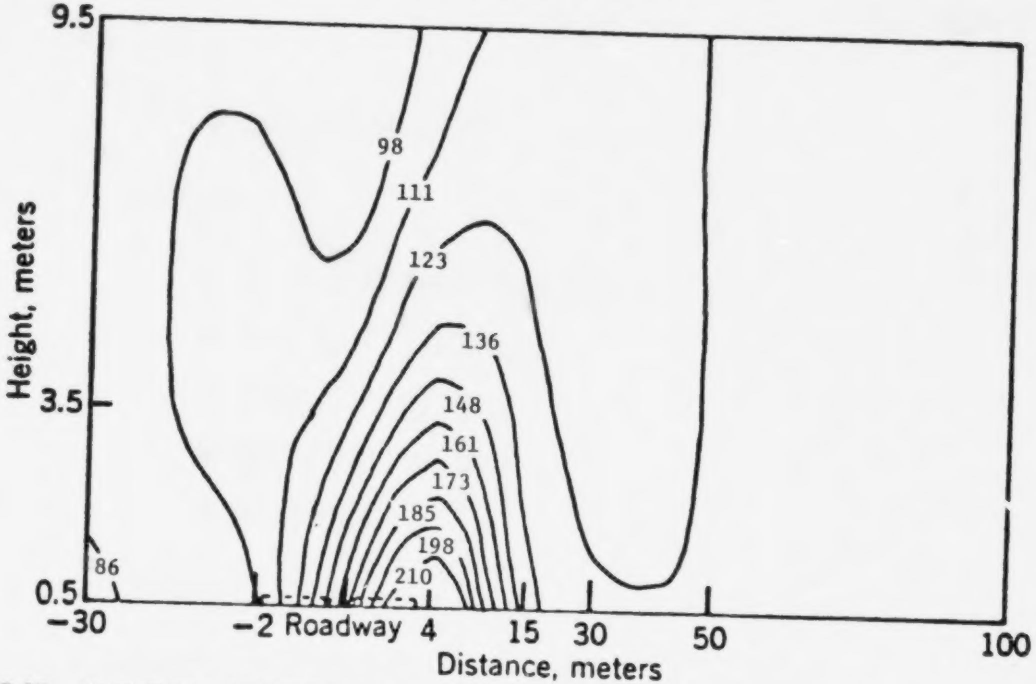
I have some reservations about the quality of input informati mation available and, also, the ability of these models to handle diesel particulate. These models can probably handle diesel particulate as well as CO, but some people suggest that the results obtained for CO are marginal.

May I have the next slide, please. (LDV-7)

We will hear this afternoon, I suspect, quite a bit about human exposure. The species of interest has to be identified. We have talked about that to some depth already. The concentration is important, for the concentration combined with the duration yield the dosage or exposure. We need to discuss how the various pollutants enter the body to determine the ultimate health impact.

I will leave the health impact potential on humans to the afternoon session, since health impacts are not my field of specialty. I would like to make some comments on what I term the welfare impacts: the economic or nuisance type impacts. The next slide. (LDV-8) Diesel emissions will impact visibility. If you start

CONTOURS RATIOED FOR DIESEL PARTICULATE
EMISSIONS ($\mu g/m^3$)



SOURCE: "GENERAL MOTORS SULFATE DISPERSION EXPERIMENT:
EXPERIMENTAL PROCEDURES AND RESULTS"
STEVEN H. CADLE et al., JAPCA 27:1, pp. 33-38

11/2/77

W8561

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IMPACT ASSESSMENT

AMBIENT AIR QUALITY MODELS

INPUTS

- FLEET MIX
- EMISSION FACTORS
- TRAFFIC VARIABLES
- SITE DESCRIPTORS
- METEOROLOGICAL VARIABLES

OUTPUT

- CONCENTRATIONS

4/21/78

LDV-6

X7504

IMPACT ASSESSMENT

EXPOSURE

- SPECIES OF INTEREST AND ATMOSPHERIC BEHAVIOR
- CONCENTRATION
- DURATION
- METHOD OF ENTRY TO HUMAN BODY

4/21/78

LDV-7

X7504

IMPACT ASSESSMENT

HEALTH AND WELFARE IMPACTS

- HEALTH IMPACT POTENTIAL ON HUMAN RECEPTORS
- WELFARE IMPACTS
  - PARTICULATES - VISIBILITY
    - BUILDING AND WINDOW BLACKENING
  - ODOR - NUISANCE

4/21/78

LDV-8

X7504

thinking about five or six thousand vehicles, all dieselized, traveling down a roadway, emitting 0.5 grams of particulates per mile, it is fairly easy to envision a black cloud hanging overhead. How acceptable that will be to society is one of the questions that needs to be addressed by the industry and government.

Associated with particulate emissions is building blackening or soiling; windows and walls getting dirty quicker. There is an obvious economic impact associated with increased soiling.

Odor. I have discussed this emission with Dr. Phil Levins on occasion, trying to figure out how to measure it, how to model it, and how to assess its impact. He will, hopefully, give us some insights in his presentation. I think odor is a real state-of-the-art problem. (Ed. note: In the panel discussion, Dr. Levins added irritants to the list of pollutants having direct welfare impacts, which the author gratefully acknowledges and accepts.)

The next slide, (LDV-9) summarizes where I think we are in trying to handle some of the questions raised at this workshop.

The first conclusion, verified yesterday, is that much uncertainty exists with the emission factors for diesels. How we can project those emission factors through the year 2000 is a major question. There is controversy around the measurement techniques of what we are measuring and, also, what we should be measuring. The estimates of how many diesels we are going to have in the passenger auto fleet in 1985 or 1995 vary widely. I don't think anyone can make realistic projections until the early 80's, when we start getting some feedback on both the design variables that the manufacturers are dealing with and, also, the consumer acceptability of diesel powered automobiles.

As I stated previously, if a problem exists with diesel particulate emissions, I suggest to you that these emissions are going to become objectionable first in heavily congested cities on our East Coast where the streets are narrower, and where we have

IMPACT ASSESSMENT

STATUS:

- CURRENT AND PROJECTED EMISSION FACTORS FOR LDV-DIESEL CONTAIN MUCH UNCERTAINTY
- MEASUREMENT TECHNIQUES FOR DIESEL PARTICULATE AND PARTICULATE/ORGANICS REQUIRE ADDITIONAL DEVELOPMENT
- LDV-DIESEL PENETRATION PROJECTIONS CONTAIN MUCH UNCERTAINTY (ALSO FOR MDT)
- IF PROBLEM EXISTS WITH DIESEL PARTICULATE AND ODOR EMISSIONS, MOST PROBABLE SITES ARE CBD STREETS (IN OLDER EAST COAST CITIES) AND OVER AND NEAR URBAN FREEWAYS
- AVAILABLE AIR QUALITY DISPERSION MODELS, IF USED TO MODEL DIESEL PARTICULATE EMISSIONS, INTRODUCE ADDITIONAL UNCERTAINTIES

4/21/78

LDV-9

X7504

large numbers of new cars. The impacts will also be significant along major travel corridors, i.e., urban freeways.

The last comment is directed to air quality dispersion models. I am not convinced that they give us the right answer because I don't think there is a right answer. In defending the use of air quality dispersion models, it is important to remember that they are only analytic tools to be used in support of decisions, not the decision mechanism itself. I think we should be aware that there are uncertainties associated with any modeling activity.

Thank you very much.

MR. GROEBECKER: Thank you, Joe Sturm.

The next speaker will be Karl Van Cauwenberghe of the Department of Chemistry of the University of California who will present a paper prepared jointly by himself, Arthur Winer, and Jim Pitts entitled,""Atmospheric Reactions of Particulate PAH and Some Biological Implications."

Karl Van Cauwenberghe.

ATMOSPHERIC REACTIONS OF PARTICULATE PAH AND SOME BIOLOGICAL IMPLICATIONS

Karel Van Cauwenberghe, Arthur M. Winer and James N. Pitts, Jr.

Statewide Air Pollution Research Center
University of California
Riverside, California 92521

DR. VAN CAUWENBERGHE: Mr. Chairman, ladies and gentlemen, the purpose of my talk today is to present some results of our investigations at the Statewide Air Pollution Research Center of the University of California, Riverside on the chemical reactivity of polycyclic aromatic hydrocarbons in real and simulated atmospheres.

Some of these data were already presented briefly by Dr. Pitts yesterday, and I would like to go into some more detail on these results.

PAH are formed in high temperature combustion processes and are detected in ambient particulates as well as in exhaust from gasoline and diesel engines. The major point I want to make is that such polycyclic aromatic hydrocarbons, when adsorbed on a surface, can react readily with gaseous pollutants found in the atmosphere, and in that process reaction products can be formed which are shown to be direct mutagens in the Ames test.

First let me sketch for you the background of the problem. It has been known for more than three decades that the organic fraction of airborne particulates is carcinogenic in experimental animals. This carcinogenicity has been mainly attributed to the presence of several polycyclic aromatic hydrocarbons, such as benzo-a-pyrene, benz-a-anthracene, and the dibenzanthracenes in the neutral fraction of the organic extract.

In addition to the polycyclics there are also several carcinogenic heterocyclic (i.e., nitrogen containing) aromatics present in the basic fraction of ambient air aerosols. Examples of these compounds are the benzacridines and the dibenzacridines which have also been shown to be carcinogenic.

Analytical methods for the quantitative determination of such species include fluorescence, gas chromatography combined with selective mass spectrometric detection and high pressure liquid chromatography.

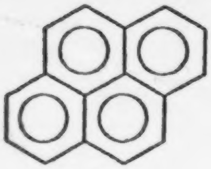
The first slide lists some of the most common polycyclic aromatic hydrocarbons found in particulates. These only go up to coronene, but yesterday we heard from Mr. Cornetti of Fiat that there may be at least another 50 percent mass of polycyclics in the higher molecular weight range which also might be very important in terms of chemical reactivity of these compounds.

As Dr. Pitts pointed out yesterday, however, the observed carcinogenicity in animals or the transformations in cell cultures is significantly greater than can be accounted for on the basis of the measured PAH content of the samples, and that is true both for ambient particulates and for automobile exhaust.

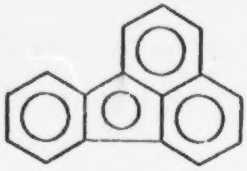
Thus, for instance, Gordon and coworkers found that the benzene extract of airborne particulates had about 100 to 1000 times the cell transformation capacity attributable to its BaP content and the subsequent methanol extract had activity comparable to the benzene extract. This is what we call the excess carcinogenicity problem. It has also been shown by Grimmer that a similar problem exists for automobile exhaust.

A second point I want to introduce is the use of the Ames test for screening these complex samples for mutagenic activity. As we all know

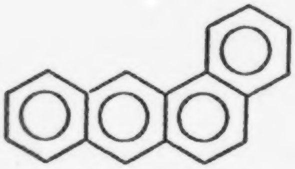
COMMON POLYCYCLIC AROMATIC HYDROCARBONS IN PARTICULATE MATTER



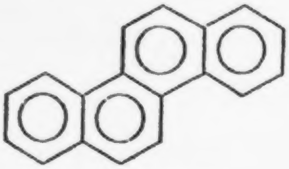
PYRENE



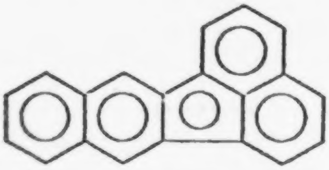
FLUORANTHENE



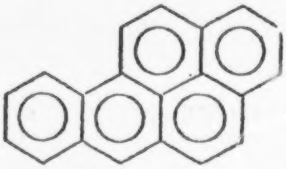
BENZ(A)ANTHRACENE



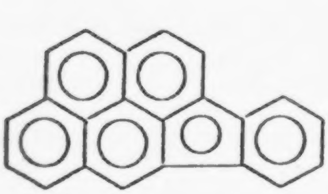
CHRYSENE



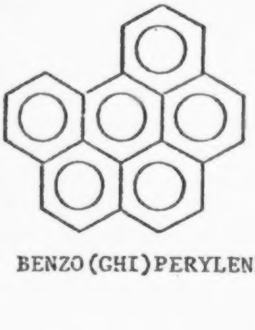
BENZO(K)FLUORANTHENE
[ALSO (B) AND (J) ISOMERS]



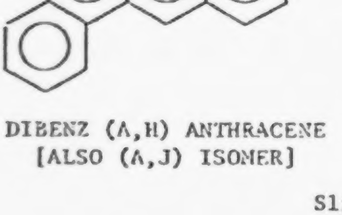
BENZO(A)PYRENE
[ALSO (E) ISOMER]



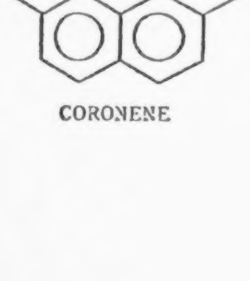
INDENO (1,2,3-CD)PYRENE



BENZO(GHI)PERYLENE



DIBENZ (A,H) ANTHRACENE
[ALSO (A,J) ISOMER]



CORONENE

Slide 1

animal tests for suspected carcinogens are time consuming and expensive. Recently a fast inexpensive microbiological assay has been developed by Ames and coworkers that is based on the reverse mutation of histidine deficient mutant bacterial strains of Salmonella typhimurium.

It has been shown by Ames that a good correlation exists between the presence or the absence of mutagenicity on one hand and carcinogenicity on the other, although there are a number of exceptions.

Basically there are two ways for performing the Ames test as shown on slide 2.

One can perform the Ames test, without metabolic activation, illustrated on the left part of the slide. We just apply the test sample dissolved in DMSO onto the petri dish, and if we do observe a growth of mutant colonies that means there is a direct mutagen present in the sample.

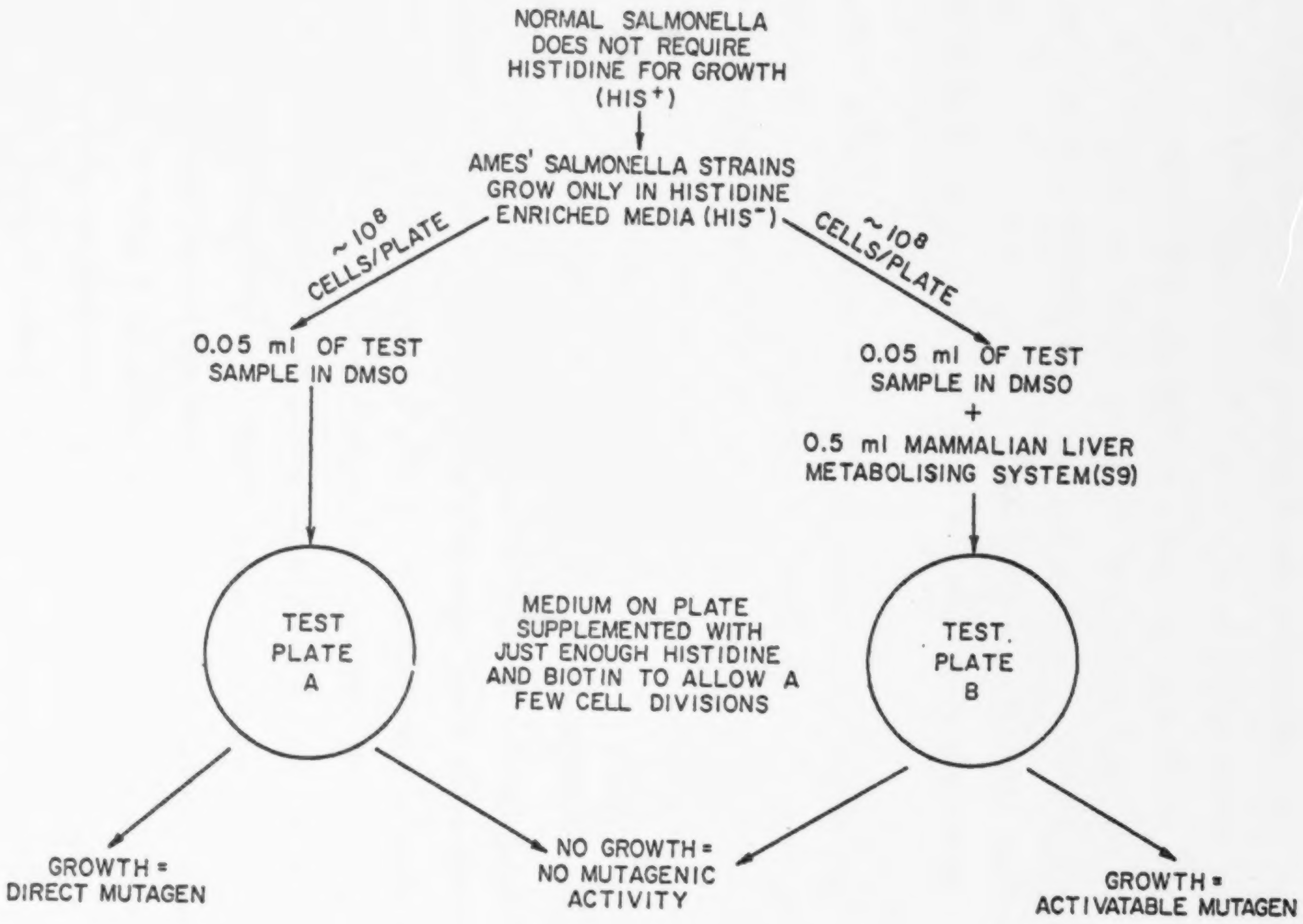
Another way of performing the test would be to add to the plate, together with the sample, a rat liver homogenate which is a microsomal activation system that transforms the compounds into active mutagens. In that way we can detect a compound that may not be mutagenic by itself, but its reaction products, the metabolites of the compound are. That is what we call an activatable mutagen or a pro-mutagen.

Let me show you some example of this test in the next few slides.

Slide 3 shows an example of mutagenicity without activation, i.e. the direct mutagenicity of benzo-a-pyrene and its metabolites in the Salmonella test. The formula of benzo-a-pyrene is given in the top part of the slide. Benzo-a-pyrene (BaP) is not a direct mutagen. It requires metabolic activation. Therefore, I have labeled it minus.

Of all the known metabolites in liver metabolism of BaP there are a couple which are direct mutagens. For instance, all of the known epoxides

AMES TEST FOR MUTAGENIC ACTIVITY



NORMAL SALMONELLA DOES NOT REQUIRE HISTIDINE FOR GROWTH (HIS^+)

AMES' SALMONELLA STRAINS GROW ONLY IN HISTIDINE ENRICHED MEDIA (HIS^-)

~10^8 CELLS/PLATE

0.05 ml OF TEST SAMPLE IN DMSO

TEST PLATE A

GROWTH = DIRECT MUTAGEN

NO GROWTH = NO MUTAGENIC ACTIVITY

~10^8 CELLS/PLATE

0.05 ml OF TEST SAMPLE IN DMSO
+
0.5 ml MAMMALIAN LIVER METABOLISING SYSTEM(S9)

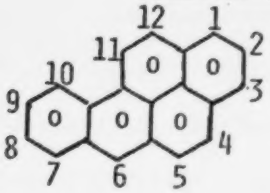
TEST. PLATE B

GROWTH = ACTIVATABLE MUTAGEN

MEDIUM ON PLATE SUPPLEMENTED WITH JUST ENOUGH HISTIDINE AND BIOTIN TO ALLOW A FEW CELL DIVISIONS

Slide 2

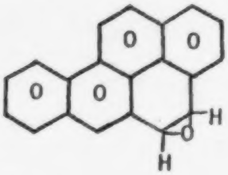
MUTAGENICITY WITHOUT ACTIVATION OF BENZO(A)PYRENE METABOLITES IN SALMONELLA TYPHIMURIUM



BENZO(A)PYRENE (-)

- BENZO(A)PYRENE-EPOXIDES

EXAMPLE:



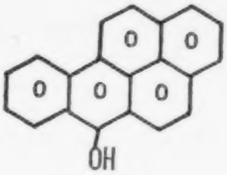
4,5 - EPOXIDE

4,5: +++
7,8: +
9,10: +
11,12: +

} UNSTABLE

- BENZO(A)PYRENE-PHENOLS

EXAMPLE:

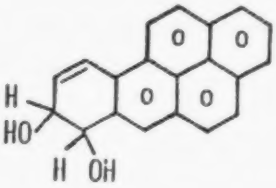


6-OH

6 AND 12: ++
1 AND 3: +
2,4,5,7
8,9,10,11: -

- BENZO(A)PYRENE-DIHYDRODIOLS

EXAMPLE:



7,8-DIHYDRODIOL

4,5: -
7,8: -
9,10: -
11,12: -

BOTH FOR CIS AND TRANS

Slide 3

of BaP are direct mutagens. Some of the phenols derived from BaP are also direct mutagens. Other isomers are not. The dihydrodiols, for instance, which can be derived from the epoxides are non-mutagenic. The quinones (slide 4), which are ultimate reaction products in metabolism, are also non-mutagenic. Also, there is a very special compound, the dihydrodiol epoxide, that is suspected to be the ultimate carcinogen. Several geometric isomers of that compound are strong direct mutagens, but it is also a very unstable compound. When that compound reacts with water, ring opening occurs, yielding a tetrahydrotetrol for which no data are available. But this is expected to be non-mutagenic. These are data from the reference that is cited below on the slide.

Our laboratory has been working for some time now on a research program of chemical characterization of the mutagens present in ambient particulate matter, and we are using the Ames test to obtain microbiological clues for the nature of the compounds that would be responsible for the observed excess carcinogenicity.

Results from our studies in the Californis South Coast Air Basin, the LA Basin, showed that all samples were directly mutagenic. They did not require any metabolic activation when tested on the strains which respond to frameshift mutation.

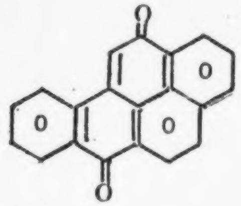
There was no response on the strains that would detect base pair substitution mutations.

Slide 5 shows dose response curves for the organic extract of the sample collected in downtown LA. We see that there is a definite response without making use of the liver homogenate for the strains TA 98, 1538 and 1537, whereas there is no response for strain TA 1535. Basically, the three strains in the top half of the slide are strains that would give some

MUTAGENICITY OF B(A)P-METABOLITES

- BENZO(A)PYRENE-QUINONES

EXAMPLE:

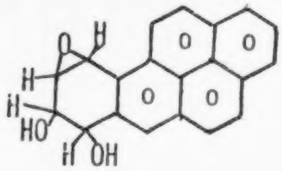


6,12-QUINONE

6,12: --
1,6: --
3,6: --
4,5: --
11,12: --

- BENZO(A)PYRENE-DIHYDRODIOLEPOXIDE

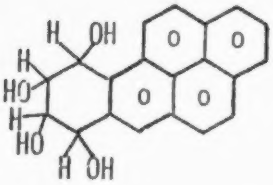
EXAMPLE:



7,8 - DIHYDRODIOL-9,10-EPOXIDE
++++
VERY UNSTABLE

- BENZO(A)PYRENE-TETRAHYDROTETROL

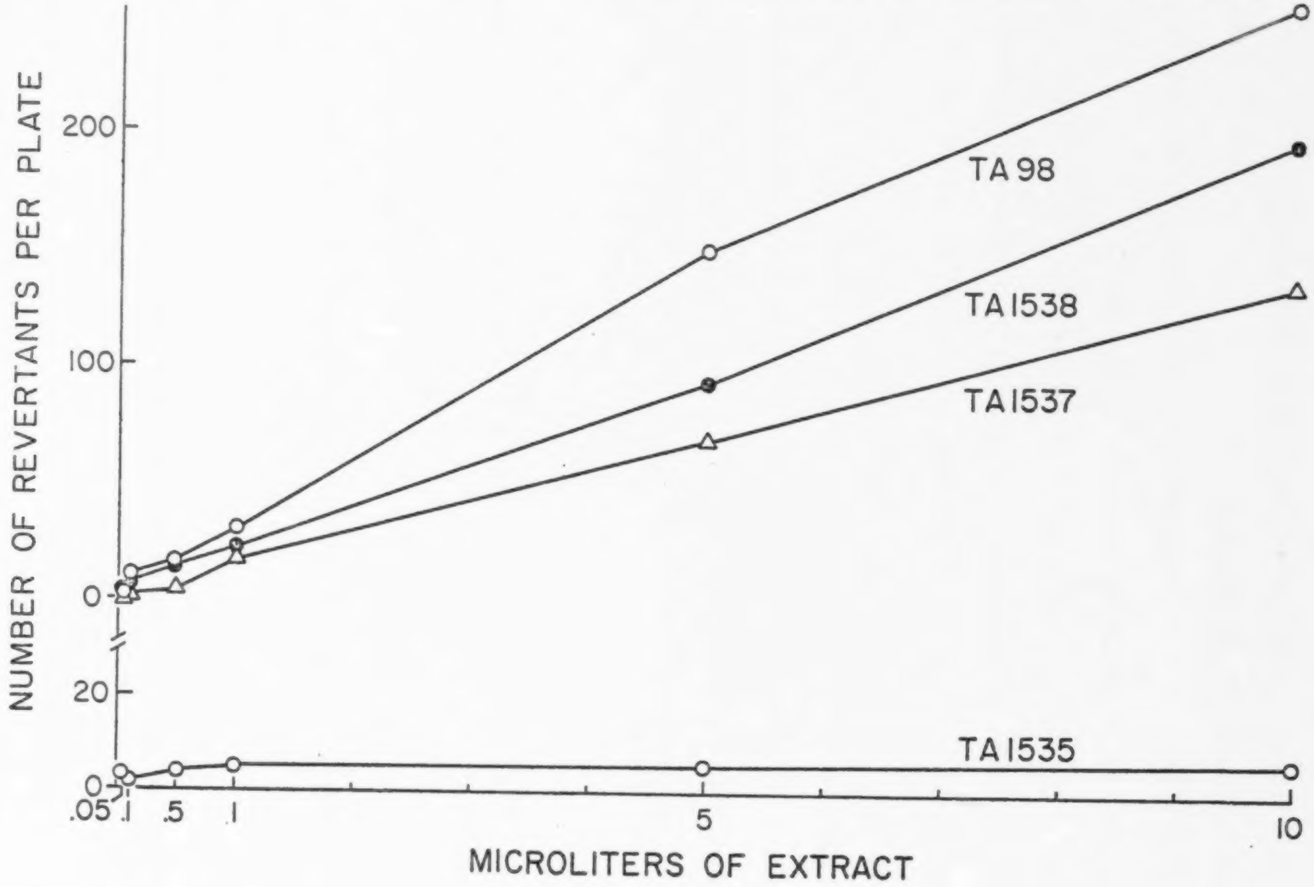
EXAMPLE:



7,8,9,10 - TETRAHYDROTETROL
NO DATA AVAILABLE

REF. P. G. WISLOCKI ET AL. CANCER RESEARCH
36, 3350-3357 (1976)

MUTAGENIC ACTIVITY OF AIRBORNE PARTICULATE ORGANIC POLLUTANTS: DOSE-RESPONSE CURVE FOR SAMPLE COLLECTED IN LOS ANGELES, CAL., SEPT. 29-OCT. 1, 1976 AND TESTED WITHOUT METABOLIC ACTIVITY



Slide 5

response for frameshift mutations, whereas TA 1535 would respond to base pair substitution mutation.

This is a very important conclusion. Furthermore, no metabolic activation was required for the samples. Thus, the PAH present in the sample, such as BaP could not account for the mutagenic activity because BaP does require metabolic activation. Also, we know from studies by Gordon and Bryan that the benzo-a-pyrene content of the particulates in the LA Basin is rather low. The average is about 1/2 nanogram per cubic meter.

Therefore, we formulated the hypothesis that this excess mutagenicity of the frameshift type could be related in part to the presence of polyaromatic hydrocarbon derivatives, reaction products in particulate matter and that these products could be direct mutagens. Additional evidence for the presence of PAH derivatives also comes from a knowledge of molecular genetics. Indeed frameshift mutations are usually associated with planar molecules capable of intercalation between the bases of the DNA strand through an interaction by an electrophilic group with the base.

Furthermore, other data from the literature also seem to point in this direction. First of all, there is some analogy with the BaP metabolites, some of which are also direct mutagens. Several reports indicate that BaP can readily undergo reaction in the adsorbed state. For instance, well known fast reactions occur on silica gel. Also, there are reports concerning the carcinogenic activity of oxidized gasoline and fuel oil products. Therefore, we undertook investigations on the chemical reactions of BaP and other polycyclics with gaseous pollutants commonly encountered in photochemical smog, such as nitrogen dioxide, ozone, PAN, etc.

A second important factor is that we have obtained some evidence that there is a difference in mutagenic activity, at least in the LA Basin, between day samples and night samples. Since pollutants such as nitrogen dioxide, ozone and PAN have very pronounced diurnal profiles, this is another clue concerning the possibility of reaction between gaseous pollutants and PAH's.

Now I am going to talk in some more detail about these reactions.

We can formulate a number of questions, as shown on slide 6. Can a typical carcinogen like BaP deposited on a filter (because that is the easiest way to perform an experiment) react with the gases in ambient photochemical smog to yield compounds that in contrast to BaP are direct mutagens? What are the products of these reactions with the different constituents of photochemical smog, such as ozone, PAN, nitrogen dioxide and so on. Are these products direct mutagens? Can other polycyclics like the non-carcinogenic perylene or pyrene also be converted into direct acting mutagens by reaction with ambient smog or its constituents? And finally, are any of these reaction products carcinogenic?

These are the basic questions. Now, let me discuss data we have obtained which bear on answers to all but the last of these questions. Certainly the answer to the last question is still an open point.

First of all, let me show you how we carried out experiments to study reactions of BaP with ambient smog.

In these studies we have coated a glass fiber Gellman type AE filter with BaP in low amounts, about 2 milligrams, as shown in slide 7. The filter is placed in a conventional high volume sampler (as the bottom filter). On top of this BaP coated filter there is a clean glass fiber filter, the purpose of which is to filter out ambient particulate matter,

QUESTIONS

1) CAN BENZO(A)PYRENE, DEPOSITED ON A FILTER, REACT WITH THE GASES IN AMBIENT PHOTOCHEMICAL SMOG TO YIELD COMPOUNDS THAT, IN CONTRAST TO BAP, SHOW MUTAGENIC ACTIVITY WITHOUT MICROSOMAL ACTIVATION?

2) WHAT ARE THE PRODUCTS OF THE REACTIONS OF BAP WITH MOLECULAR OXYGEN AND THE INDIVIDUAL OXIDANTS PRESENT IN TYPICAL PHOTOCHEMICAL SMOG, E.G. O_3, PAN, NO_2, ETC.

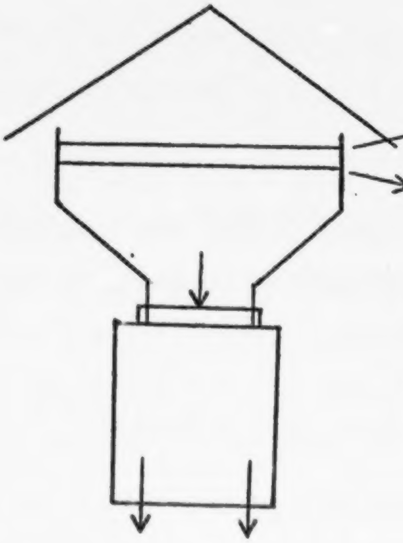
3) ARE THESE PRODUCTS DIRECTLY MUTAGENIC IN THE AMES TEST?

4) CAN NON-MUTAGENIC, NON-CARCINOGENIC PAH SUCH AS PERYLENE BE CONVERTED TO DIRECT ACTING MUTAGENS BY AMBIENT SMOG OR ITS CONSTITUENTS?

5) ARE ANY OF THESE CARCINOGENIC?

Slide 6

HIGH VOLUME SAMPLER



UPPER FILTER (GELMAN A/E)

BaP-COATED FILTER (GELMAN A/E)

AIR FLOW 40 SCFM

MOTOR

thus letting only the gases pass through onto the second filter where they could undergo reaction with the BaP.

We have shown, of course, that there is no transfer of ambient particulates or mutagenic activity from that first filter onto the second one in a blank experiment. In our experiments we exposed a 2 milligram sample of BaP coated onto the glass fiber filter to ambient photochemical smog at typical flows of 40 standard CFM for about 72 hours.

Basically, this is a dark experiment because the filter is covered by another filter and both are also covered by the rooftop of the sampler.

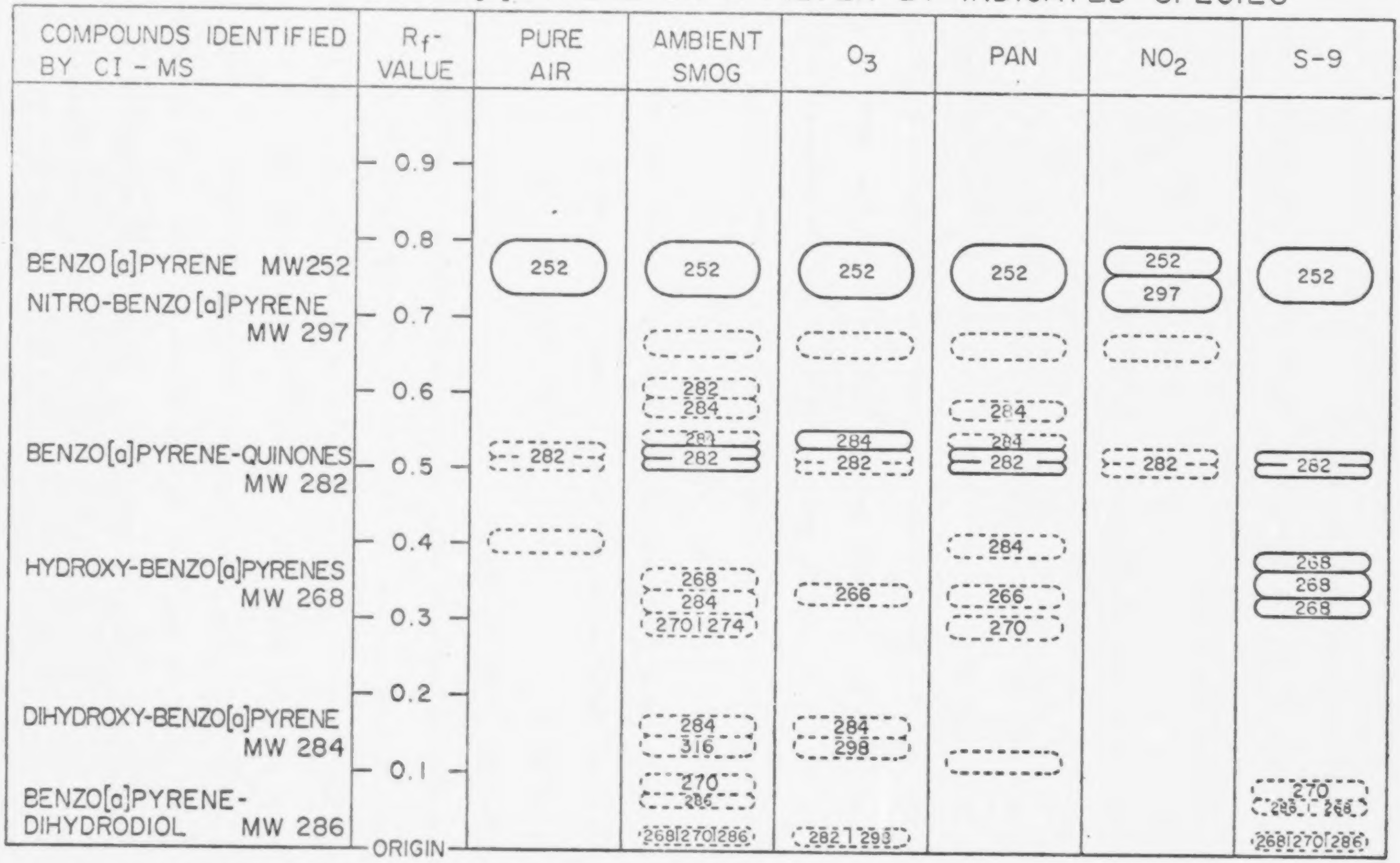
After the exposure as described, we extracted the reaction products from the filter, and ran the Ames test to check for direct mutagenic activity. The answer to our first question was yes, there is direct mutagenic activity from species formed by reaction of the constituents of ambient smog with BaP.

Next we carried out TLC separations of these reaction products.

Slide 8 contains a great deal of information. You can see that the second experiment, labeled ambient smog, yielded a large number of spots each representing different compounds that are formed by reaction of BaP with constituents of ambient smog.

We have already tried to carry out some preliminary identifications of some of these spots by recovering the spot in methanol and running the chemical ionization mass spectra of a direct probe sample. You see in the left column some of our tentative identifications of compounds. Of course, well-known products are the benzo-a-pyrene quinones, but these are non-mutagenic. So, they are not that interesting to us. But there are several other compounds which are quite interesting. Thus, there appear to be some benzo-a-pyrene phenol(s), also called hydroxybenzo-a-pyrenes, formed in the ambient exposure experiment. There also seem to be some traces of dihydroxy-

MOLECULAR WEIGHTS AND TENTATIVE ASSIGNMENTS OF TLC FRACTIONS FOLLOWING TREATMENT OF BENZO[a]PYRENE ON A FILTER BY INDICATED SPECIES



SOLVENT : TOLUENE/DICHLOROMETHANE/METHANOL 25/10/1

Slide 8

compounds and benzo-a-pyrene dihydrodiol(s).

In another series of investigations we carried out exposures of benzo-a-pyrene on glass fiber filters with simulated atmospheres. Basically, these were 24-hour experiments in which we exposed the BaP to nearly ambient levels of common pollutants in photochemical smog, such as nitrogen dioxide (containing ppb traces of nitric acid), ozone, and peroxyacetyl nitrate (PAN). For ozone we used approximately 10 ppm concentration levels and for PAN and NO_2 about 1 ppm concentrations. Again the total extracts of the three reaction mixtures were directly mutagenic in the Ames test. We also carried out TLC separation on these mixtures. We obtained a number of spots, some of which correspond to the spots we found for the ambient air exposures.

As a control we also did an experiment in which we subjected BaP to the action of the rat liver homogenate enzyme system and formed several metabolites of BaP which are well known from the literature. These were quinones, phenols and traces of dihydrodiol(s).

What are the conclusions from these experiments?

Some of them are shown in slide 9. First of all, there seems to be a pattern of mutagens resulting from the exposure of BaP to ambient photochemical smog that can largely be reconstituted by combining the single effects of ozone on BaP and peroxyacetyl nitrate on BaP.

Furthermore, there seem to be other compounds in the ambient exposure that have similar retention (R_f values) as the BaP phenols and also were shown by mass spectrometry to give the same molecular weights. So, probably there are also BaP phenols formed in the ambient exposures.

The exposures of BaP to nitrogen dioxide containing traces of nitric acid (HNO_3) appeared to give almost exclusively nitrobenzo-a-pyrenes.

CHEMICAL AND MUTAGENIC ANALYSIS OF PRODUCTS RESULTING FROM EXPOSURE OF BaP TO NO_2, O_3, PAN, S-9 AND AMBIENT PHOTOCHEMICAL SMOG

1) THE PATTERN OF MUTAGENS RESULTING FROM EXPOSURE OF BaP TO AMBIENT PHOTOCHEMICAL SMOG CAN BE LARGELY RECONSTITUTED BY COMBINING THE EFFECTS OF OZONE AND PAN ON BaP.

2) METABOLITES GENERATED BY TREATMENT OF BaP BY RAT LIVER HOMOGENATE ARE COINCIDENT WITH FRACTIONS FOUND IN AMBIENT SMOG IN BOTH MW AND MUTAGENICITY.

3) THE REACTION OF BaP WITH NO_2 SEEMS TO GIVE ALMOST EXCLUSIVELY NITROBENZO(a)PYRENE. THIS SPECIES IS HIGHLY MUTAGENIC AND INDUCES FRAMESHIFT MUTATIONS IN *SALMONELLA TYPHIMURIUM*. TO OUR KNOWLEDGE THIS COMPOUND HAS NOT PREVIOUSLY BEEN REPORTED TO BE MUTAGENIC.

4) THE FRACTION CONTAINING THE BaP PHENOL ISOMERS (MW 268) IS MUTAGENIC IN BOTH AMBIENT SMOG FRACTIONS AND IN BaP ACTIVATED BY S-9.

5) CARE MUST BE EXERCISED IN INTERPRETING CARCINOGENIC AND MUTAGENIC RESULTS OF SAMPLES COLLECTED ON HIGH VOLUME FILTERS BECAUSE OF POSSIBLE FILTER ARTIFACTS.

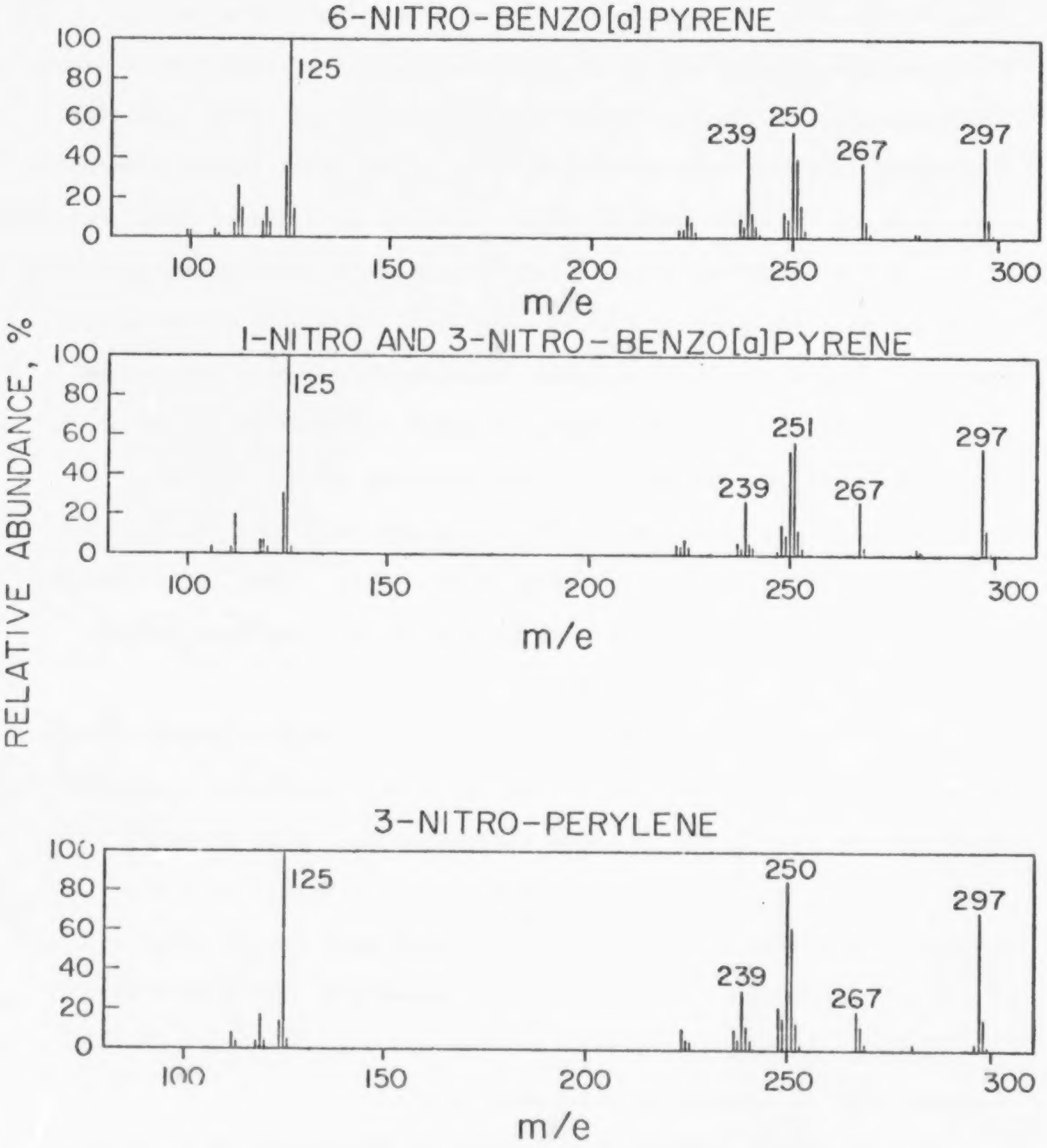
These species were highly mutagenic, in fact, they were the strongest direct mutagens we observed in all of our exposures, and they induced frameshift mutations, of course. To our knowledge this is the first time that these nitro-compounds have been reported to be mutagenic. Again I emphasize that there are no data available yet on the carcinogenicity of these compounds.

Since the experiment with the exposure of BaP to nitrogen dioxide (with traces of HNO_3) was a rather "clean" experiment giving only a limited number of reaction products, we looked somewhat further into that system. It is important to notice that traces of nitric acid must be present at the ppb level in the NO_2-air mixture for the nitration reaction to occur.

We changed the solvent system of our TLC separation and were able to separate the nitrobenzo-a-pyrenes into three isomers. These three isomers were then further identified by their UV spectra and their mass spectra. The UV spectra are reported in the literature.

In this way we determined that there are three nitro-compounds formed in the gas phase (acid catalyzed) nitration of BaP coated onto a surface. There were the 6-nitro BaP (a yellow compound with a yield of about 30 percent after an 8-hour exposure) and a mixture of the 1- and the 3-nitrobenzo-a-pyrene. The latter are orange compounds with a lower yield of about 20 percent. Authentic samples of these compounds were synthesized by nitration in solutions of BaP as reported by Dewar and coworkers and were compared with the observed reaction products.

On slide 10 are shown the mass spectra of the 6-nitro and 1- or 3-nitro compounds. The 1- and 3-nitro-BaP's can be separated on glass capillary columns, but it is difficult to separate them on TLC. The mass spectra showed the typical loss of nitric oxide followed by a loss of carbon monoxide, as expected for aromatic nitro compounds.



6-NITRO-BENZO[a]PYRENE

1-NITRO AND 3-NITRO-BENZO[a]PYRENE

3-NITRO-PERYLENE

Slide 10

Now what were our results with respect to the mutagenicity of these compounds? Well, all nitro-BaP's were direct mutagens of the frameshift type. The 6-nitro-BaP was a moderate direct mutagen. The mixture of the 1- and the 3-nitro-BaP was a strong mutagen. Also, there appeared to be enhancement of mutagenic activity with metabolic activation. The dose response curves that we obtained are shown in slide 11.

In the left upper corner is a dose response curve for BaP itself. As discussed previously, there is no mutagenic activity without rat liver homogenate activation, while there is strong mutagenic activity upon metabolic activation.

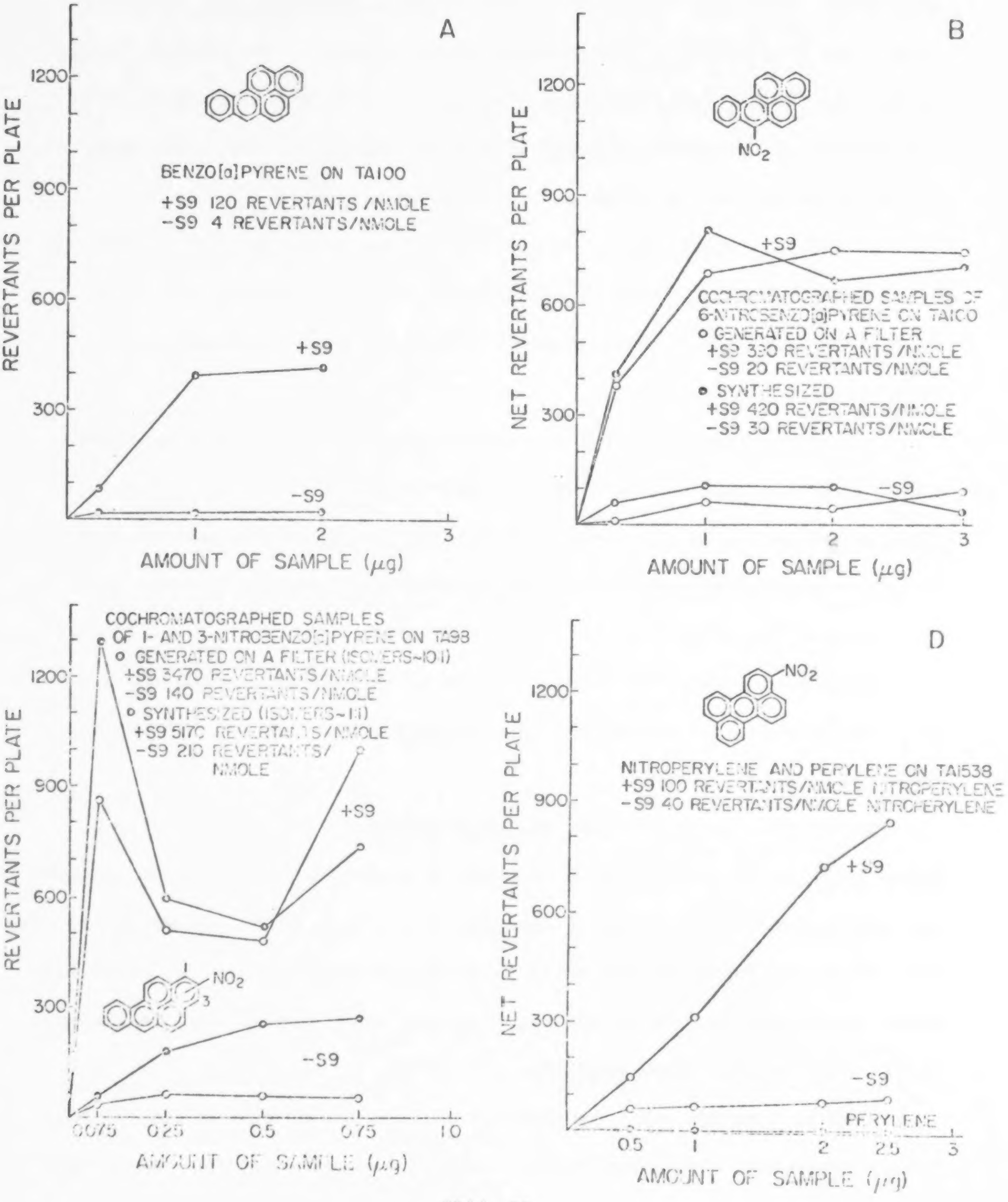
As you can see from the lower curve, the 6--nitro-BaP is a moderate mutagen without metabolic activation while it turns out to be a strong mutagen upon activation. The filled circles are the points we obtained with the synthesized samples and the open circles are the data points we obtained for the samples taken from the ambient exposure.

Also, you can see the curves for the mixture of the 1- and the 3-nitro BaP's which are strong mutagens without activation but even stronger mutagens upon activation.

Let me also point out that the data for the chemical reactivity of benzo-a-pyrene on a filter with nitrogen dioxide are in good agreement with the calculated distributions of electron densities. Thus, one would predict that nitration (which is basically an electrophilic substitution reaction) would occur most readily in the six-position, more readily than in the one position, or in the three position.

Another question which we have raised, and it was raised also by Dr. Pitts, yesterday, is the following. Could a non-carcinogenic, non-mutagenic polycyclic aromatic hydrocarbon closely related to BaP, for instan

DOSE RESPONSE CURVES OF:



Slide 11

perylene, also be converted into a nitro-derivative and could that nitro-derivative also be a direct mutagen?

To answer this question we have performed appropriate experiments with perylene.

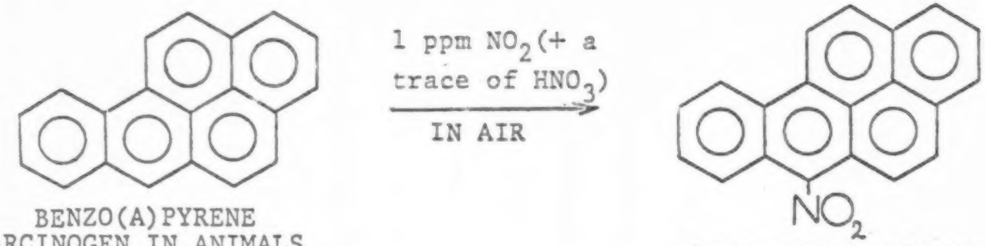
Slide 12 summarizes our data concerning the nitration experiments for benzo-a-pyrene and perylene. Perylene itself, is also a pentacyclic polyaromatic hydrocarbon, but it is known to be a non-carcinogen and non-mutagenic in the Ames' reversion assay. As you can see perylene can be readily transformed to 3-nitroperylene, the only isomer which seems to be formed. 3-Nitroperylene was shown to be a moderate direct mutagen. I showed the dose response curve already in the bottom righthand section of the previous slide (11).

The yields of 3-nitroperylene were also significant and again some enhancement of mutagenic activity upon metabolic activation was observed.

Furthermore, we carried out some additional experiments using other types of polycyclics such as pyrene which is a quadricyclic compound. Pyrene was also shown to be nitrated in a 1 ppm atmosphere of nitrogen dioxide (containing traces of HNO_3) in air, but the yields are much lower, as would be expected from analogy with the reaction rates of aromatic nitration in solution for pyrene.

A final question one might ask is what will be the ultimate fate of these nitropolycyclics? We have done one experiment to provide some preliminary answers to this question. Thus, we carried out irradiation experiments on the 6-nitrobenzo-a-pyrene coated on silica gel, and found that in a matter of hours significant yields of the quinones were obtained. The quinones I should remind you are non-mutagenic. These observations are consistent with the Chapman mechanism proposed for the transformation of nitroanthracene to the 9,10-anthraquinone upon irradiation.

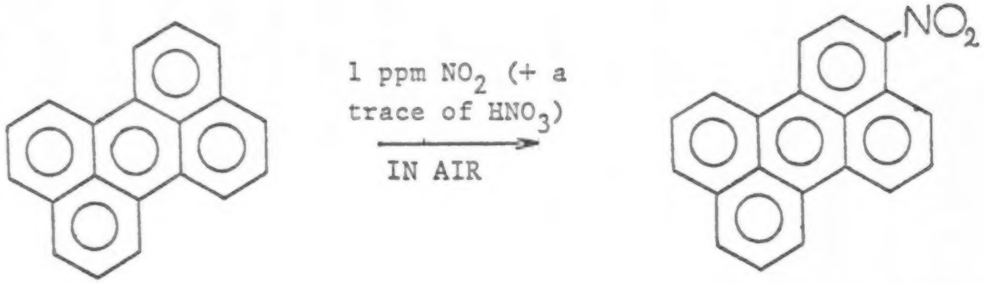
REACTIONS OF A PARTICULATE CARCINOGENIC AND A PARTICULATE NON-CARCINOGENIC POLYCYCLIC AROMATIC HYDROCARBON WITH NITROGEN DIOXIDE CONTAINING A TRACE OF NITRIC ACID IN A SIMULATED ATMOSPHERE



$\xrightarrow[\text{IN AIR}]{\text{1 ppm } NO_2 \text{(+ a trace of } HNO_3\text{)}}$

BENZO(A)PYRENE
CARCINOGEN IN ANIMALS
PROMUTAGEN IN AMES'TEST

6-NITROBENZO(A)PYRENE
(ALSO 1 and 3-NITRO-ISOMERS)
DIRECT MUTAGENS IN AMES TEST
? CARCINOGEN



$\xrightarrow[\text{IN AIR}]{\text{1 ppm } NO_2 \text{ (+ a trace of } HNO_3\text{)}}$

PERYLENE
NON-CARCINOGEN
NON-MUTAGEN IN AMES' TEST

3-NITROPERYLENE
DIRECT MUTAGEN IN AMES TEST
? CARCINOGEN

Slide 12

In conclusion I would like to make some comments on the environmental implications of our results. Clearly, the facile formation of directly mutagenic nitro-derivatives from the exposure of both non-carcinogenic and carcinogenic polycyclics (coated onto a surface) to nearly ambient nitrogen dioxide levels (with traces of HNO_3) warrants further investigation with respect to the atmospheric reactions and the ultimate fates of these compounds. This is especially needed to understand situations where high levels of polycyclics on particulates and high levels of nitrogen dioxide might coexist, such as in diesel exhaust or in plumes from coal fired powerplants.

Furthermore, not only must one consider the reactions of nitrogen dioxide or ozone or PAN with respect to the production of direct mutagens, but also electrophilic attack on the polycyclics by such key species as the hydroxyl radical (the most important chain-carrier in photochemical smog) and singlet molecular oxygen which could be readily formed by an energy transfer mechanism from the excitation of the BaP itself, upon irradiation. Recall that in the ambient exposures of BaP we did find some compounds which are suspected to be BaP phenols and these could result from a reaction either with hydroxyl radicals or with singlet oxygen followed by further transformations.

These reactions should be studied both in the dark and upon irradiation. Additionally, the experiments we have performed and described were done on glass fiber filters coated with BaP. The extrapolation of these results to atmospheric particles clearly requires a great deal of further work. For example, we must investigate the effects of (a) the nature of the particles (this would be mostly carbonaceous material in the case of diesel exhaust), (b) their average particle size, (c) the specific surface area and (d) the presence or the absence of irradiation. In view of the seriousness and urgency of the diesel exhaust particulate problem, it is essential that these crucial but difficult research problems be addressed with the utmost speed. Only in this way can we begin to definitively assess the impact of the PAH's and their reaction products, both in the atmosphere and in the exhaust system.

Finally, we wish to acknowledge support of the research presented here by the National Science Foundation-RANN (Dr. Richard Carrigan, grant monitor), the Environmental Protection Agency (Dr. Philip Hanst), the California Air Resources Board (Drs. John Holmes and Jack Suder) and the University of California. However, the views expressed here are our own and not necessarily those of these agencies or of the University of California.

Thank you.

! **MR. GROBECKER**: Thank you.

I think since we have been going nearly two hours, I will ask for a 10-minute break to stretch and perhaps you could be in your chairs in 10 minutes at 10:25.

(Brief recess.)

MR. GROBECKER: Can we resume our seats, please?

I am glad to see that you have found the coffee machine and the other elements which are necessary for our-continued happy existence and thank you for resuming places so promptly because our time this morning is full.

I am asked to make an announcement to urge those who may not have heard the previous invitation to please register at the next break at the little table just outside the door so that you may be the recipient of the proceedings.

The next speaker will present a paper presented by Charles Begeman of General Motors Company entitled Atmospheric Chemistry of Primary Particulates. The speaker who will present this paper is Jon Heuss of General Motors Company.

MR. HEUSS: Thank you very much. I guess I am pinch-hitting for Charlie again today. I would like to spend a few minutes discussing the methodology concerning factors affecting human exposure and those kind of calculations and then describe the CRC project that is now getting underway that Charlie was going to talk about. Obviously as other speakers have said, we are talking about various atmospheric phenomena that involve the dispersion and transport and a variety of physical and chemical changes between the source and the receptor. At this point we have to go back to the health people and ask from a health viewpoint what is the concern? Is it total suspended particulates, total mass? Is it the fine particulate fraction? Is it the organic fraction? Is it some individual PNA's? Is it their oxidation products as we may have heard?

So, once you get an idea of what things you want to look at, then you start trying to make the calculations, estimations or measurements. Some of these we can handle and some we cannot.

Given an emission rate, we can handle the dispersion and transport pretty well as we mentioned earlier. Because the diesel particulates are small particles they initially disperse like a gas. If you choose either total suspended particulates or fine particultes as the concern, when you look for potential problems you look for where there are either many sources or a combination of many sources and high emission rates in proximity to receptors.

So, in the diesel particulate case we would consider concentrated traffic in street canyons and around freeways and in urban central cities. We, as was pointed out, have a number of good techniques or models to use for these cases. I would mention three, two of which were already mentioned, one is the CRC APRAC dispersion model for the street canyon situation. It was tested and developed on carbon monoxide measurements.

For the freeway situation, we are quite proud of our own work that was mentioned earlier, and David Chock's simple line source model which was developed from our sulfate dispersion experiment is one we would highly recommend.

A vugraph was shown of our experiment and some of our results. We had about 352 cars running around a test tract, but we ended up with about 5,600 vehicles per hour passing the sampling line that you saw, the line of towers. We had a very controlled driving situation. This enabled us to have a quasi-real life situation where the meteorology was the only major variable.

We emitted SF_6, a gas tracer, as well as measuring the sulfate. So, we were able to map out the dispersion of both the catalyst sulfate particles and the SF_6 around the roadway, and David Chock has developed two models from our data. One is an empirical Guassian model that has plume rise built into it, and takes into account the heat and turbulence created by the traffic.

The second is a more fundamental model, an advection-diffusion model. The second model uses the turbulence data collected during the experiment to derive an eddy diffusivity tensor, appropriate for a roadway situation. We were fortunate enough to run under a variety of meteorological conditions: wind speeds, wind directions and stabilities. We were able to run under close to the most adverse conditions possible: essentially calm winds along with a steep temperature inversion. The models which we have developed are available. They are both in press now in the open literature, and they are available in report form from us.

The third technique we would recommend is just that of using other ambient measurements like carbon monoxide as a tracer and scaling up or down by the appropriate ratio of emission rates. One that I would recommend as very useful would be the lead tracer technique. Lead particulate has been studied for many years and historically we have a lot of information on the emissions of lead under a variety of driving conditions. We also have a lot of information on ambient concentrations in many locations historically. So you can scale from the existing lead ambient measurements taking into account differences in the lead and diesel emission rates. You don't have to worry about the meteorology or the traffic under these conditions. You assume it was the same as when the lead measurements were made.

However, when any of those models are used you have to be very careful to use it in a region where it has been validated in some fashion.

EPA's problems using the HIWAY model in making the initial calculations that they made about the sulfate question arose because they used it outside the range where it had been tested or validated. In all these calculations there are very many inputs and you have to check all the assumptions which to into them and be very careful about choosing realistic inputs. You have to be very careful to choose an emission rate appropriate to the circumstances because emission rates from vehicles change with driving conditions considerably. The diesel emission rate that you would plug into any of these calculations will have to take into account the emission rate per diesel vehicle which is going to be a function of model year and the number of diesel vehicles on the road. As the percent of light duty diesels being sold increases in the next few years, the actual percentage of vehicle miles traveled by diesels as a function of the overall VMT is going to increase slowly. It is going to lag behind the sales penetration in a way that a characteristic of the turnover of the fleet. I am sure that all of us who have been interested in this question have already made this calculation for ourselves, although it has not been presented at this meeting yet.

This raises an interesting distinction which I am sure we are all aware of, but has not been brought out at this meeting yet. For other emission standards that Congress has set or Congress has directed EPA to set, setting the standard for a given pollutant eventually determines the overall emissions of that pollutant from the car fleet as the car population turns over. But setting a diesel particulate standard does not uniquely determine the overall diesel emissions. The penetration is another unknown in that calculation.

We are in pretty good shape to be able to discuss and describe the dispersion process in the kind of situations that I mentioned earlier -- those that look like the ones of most interest at this point.

We are less knowledgeable about the physical and chemical changes which occur as diesel particulates are transported, and that is the reason why CRC has started a project in this area. This is the second topic I would like to talk a little bit about this morning.

This particular project is entitled Atmospheric Chemistry of Primary Particulates. Its objective is to investigate the chemical and physical changes that primary particulate emissions undergoe upon their initial dilution in the atmosphere and during their lifetime in the atmosphere.

This project was initiated in 1976, and at that time there was concern over the fate of sulphuric acid emissions from cars. The first effort of this group was put into a cross comparison and testing of analytical techniques for sulphuric acid and various other sulfate species and ammonia.

However, because of the concern only diesel particulates, a new contract effort is being started on diesel particulates, and the project group is now reviewing proposals. This contract effort will be in a number of phases. The first one involves a general characterization of the chemical and physical properties of the particles as they are emitted. The idea here is to generate diesel particulate under realistic conditions which will probably involve some sort of vehicle measurements in the field. The exact nature of those, again, are not yet determined, but a number of proposals for such work are being considered.

The kind of characterization that we are talking about includes, elemental analysis, a very general categorization of the carbonaceous material, for example, the relative amounts of aliphatic and aromatic compounds, the volatility of the organic compounds, the oxygenated portion of the organics, extractable organics versus elemental carbon and that sort of thing. We are also interested in the chemical form of the emitted particulate sulfur, whether it is sulphuric acid, sulfates tied up with the particulate in some fashion, absorbed SO_2 sulfite or any of the other possible forms. We are interested in physical characterization in terms of the size distribution, the shape and morphology of the particles, the surface area and the optical properties, light scattering, adsorption, and opacity.

The second year of the program would involve a study of the evolution of the changes of these properties with time in the atmosphere.

Examples of things that might be investigated here are the particle growth rates and changes in composition of the particles either due to desorption of organic compounds, adsorption, or chemical changes. We would also be interested in changes in the surface area and the nature of the particle surface, changes in light scattering and adsorption properties of the particles. The overall objective of this project is to form a picture of the diesel particulate emitted from the source and at longer residence times on a scale up to hours and to understand the phenomena involved in these transformations.

This work is, as I mentioned, about to get underway. It is an example of the kinds of things we have to do so understand the situation so we can make informed decisions.

Thank you.

MR. GROBECKER: Thank you, Jon Heuss.

The next speaker is Philip Levins of Arthur D. Little who will talk on the subject, "Effects of Diesel Engine Emissions on Coal Mine Air Quality."

MR. LEVINS: Thank you. I would like to share with you this morning some results from our continuing activities in the emission of unrequlated species from diesel exhaust, in particular a study of the effects of some of the toxic species on coal mine air quality. #1

This is a program that was initiated in 1975 and completed later in 1976. The report from this program is available from the project officer, Dr. Robert Freedman at the U.S. Bureau of Mines in Bruceton, Pennsylvania. The program was sponsored largely out of an effort to try to establish a real data base on some of the unregulated diesel emissions on air quality in the mine.

The excellent work of the Bureau many years ago done by people like Dick Hurn and others on carbon monoxide and nitrogen oxides emissions and ventilation requirements to establish acceptable air quality ahd led to the regulations presently in use for ventilation associated with a given engine in a coal mine.

I think the work that we have done here is useful in a larger context than the coal mine, if I can borrow the earlier definition of dispersion and concentration areas.

May I have the next slide? #2

As many of you probably know, there are not too many diesel engines down inn coal mines. They are used pretty extensively in metal and non-metal mines, about 10,000 or so in use now in North America, and all this information has been summarized very nicely in the recent NIOSH Workshops. The Martin County Coal Company in Inez, Kentucky is a non-union mine and uses diesel equipment extensively on their haulage equipment, in particular on their teletram units that carry the coal from the mining face to the conveyor system. The equipment used in that mine consists of vehicles powered largely

EFFECTS OF DIESEL ENGINE
EMISSIONS ON COAL MINE
AIR QUALITY

Prepared for

UNITED STATES DEPARTMENT OF THE INTERIOR
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by

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASSACHUSETTS

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LEVINS - 1

TABLE IV-1

Diesel-Powered Equipment Descriptions

002 Section

Vehicle	Model Number	Vehicle Manufacturer	Engine Manufacturer	Engine Model	Engine Horsepower	Ventilation Air Flow Requirement* (CFM)
Teletram	MTT-F20-18(S)	Wagner Mining Equipment Co.	Caterpillar	3306NA	150	17,000
Scooptram	ST-5D	Wagner Mining Equipment Co.	Caterpillar	3306NA	150	17,000
Personnel Carrier	6524-D	Sein Equipment Company, Inc.	Ford	201-CIB	40	13,400
006 Section						
Teletram	HMTT-410(S)	Wagner Mining Equipment Co.	Caterpillar	3304NA	81.6	12,000
Scooptram	HST-5D	Wagner Mining Equipment Co.	Caterpillar	3304NA	81.6	12,000

*Ventilation air flow required on MESA approval label for the vehicle.

by a Caterpillar 3300 series engine with a Ford engine on the personnel carrier as well.

Note that the ventilation requirements for use in the mine for the about typical 100 horsepower engine under MHSA the regulations are somewhere between 12 and 17 thousand CFM.

For those of you who have not seen coal mine layouts before this is a typical kind of pattern of a room and pillar operation #3 used at Martin County. It looks like an urban environment as well if you want to picture it that way and indeed some of the concentrations that you wind up with are closely related.

Essentially, barriers are constructed between the pillars that are left after the mining so that you have a fresh air intake to a mining face and then a return air system.

So, in many ways if we consider a working area at the face for instance, we have a microscale environment and then along the intake and return air pathways we have the mesoscale environment, and you never get to a macroscale environment in this kind of mine.

Typically in that environment we find that the dilution of diesel exhaust is about 100 to 1. That varies maybe 50 to 1 to 150 to 1, but 100 to 1 is a good average.

The other general layout showed an environment where essentially all the pathways are swept actively and very effectively with clean air going down in a mining face and returning it up.

The kind of environment, the microenvironment where the ventilation is a bit more of a problem is represented by this kind of situation #4 where we have the miner at the working face up here, and the intake air is really coming up one corridor and back down the return air duct and some effort is made to divert air into that working face environment, but it is much more difficult to drive it down there. So, the opportunity for local concentrations to build up in this sort of enviroment are much greater.

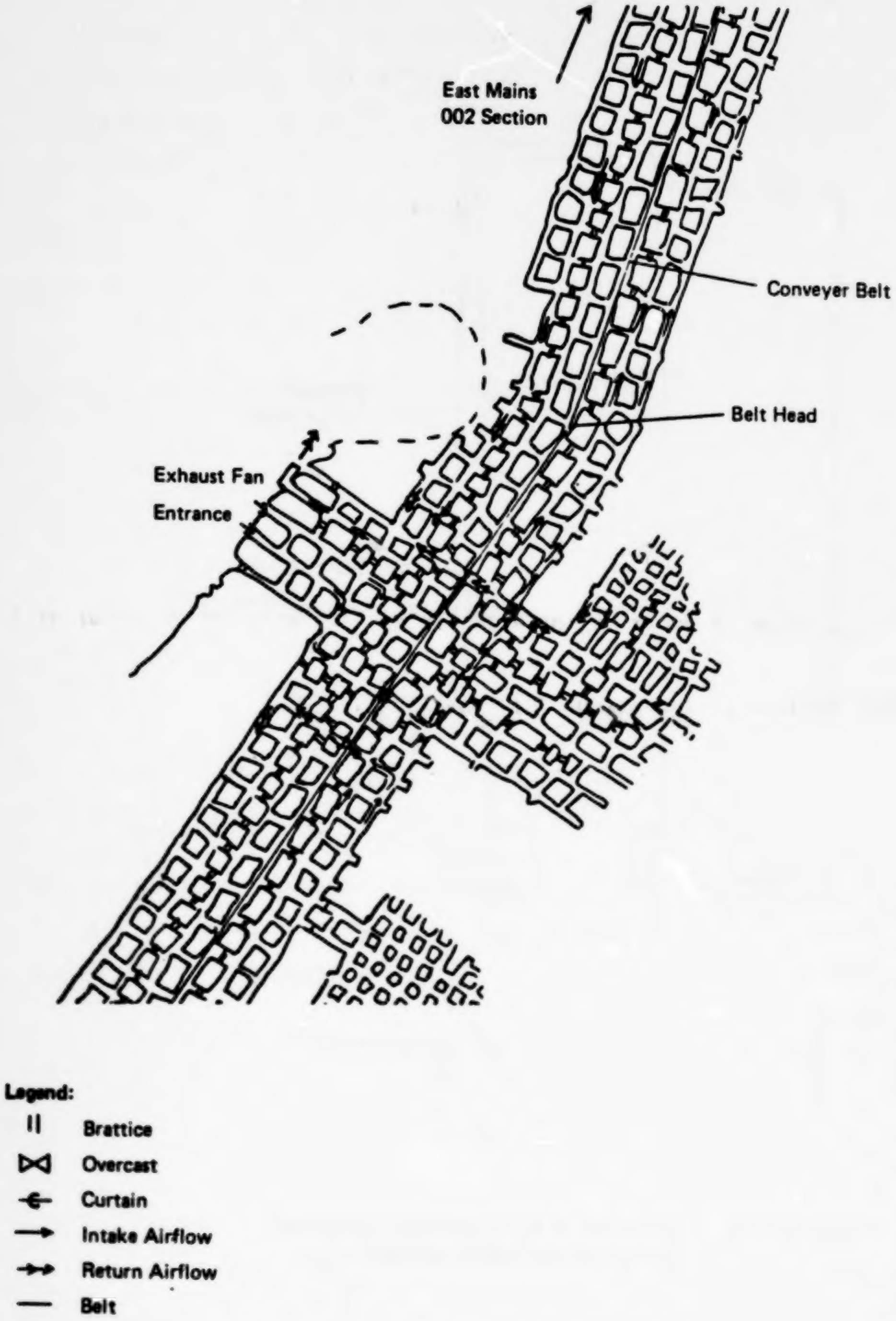


FIGURE IV–1 MAP OF EAST MAINS 002 SECTION

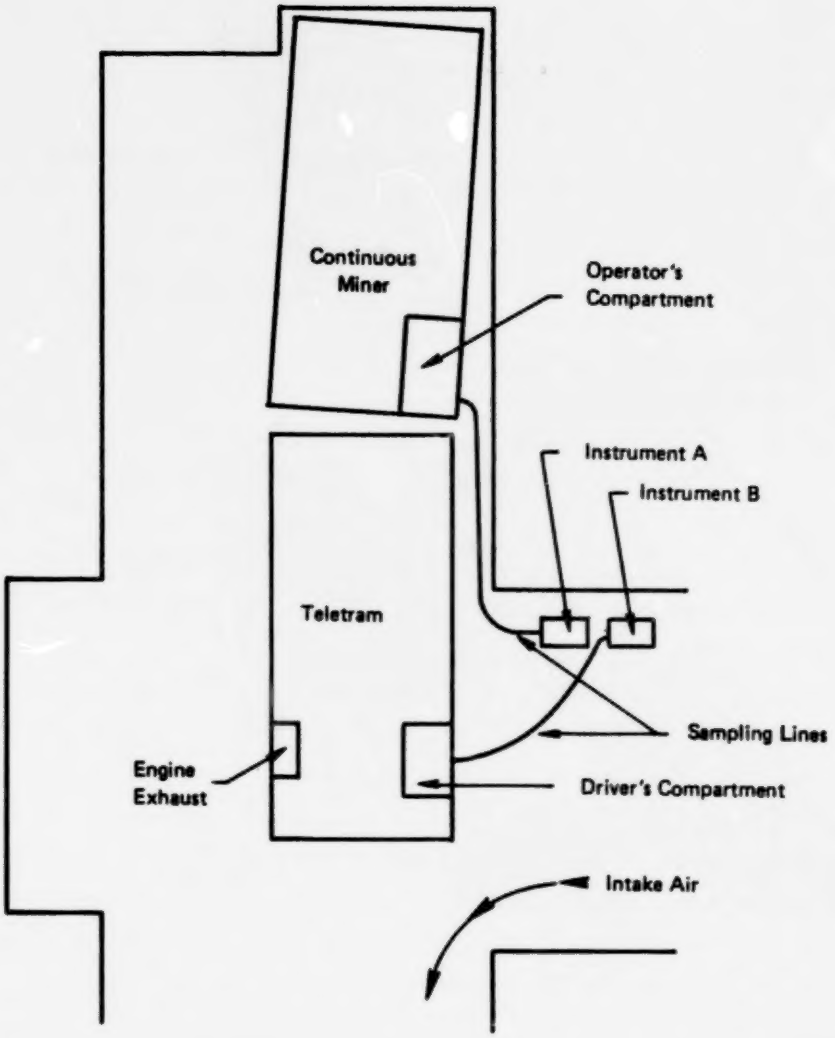


FIGURE V–9 DIAGRAM OF CUT 2 SHOWING SAMPLING LOCATION AND AIR FLOW PATTERNS

In this particular case we have an electric miner with an operator sitting there, a teletram which is a diesel powered vehicle with a scopp trailer out the back and driver's compartment there.

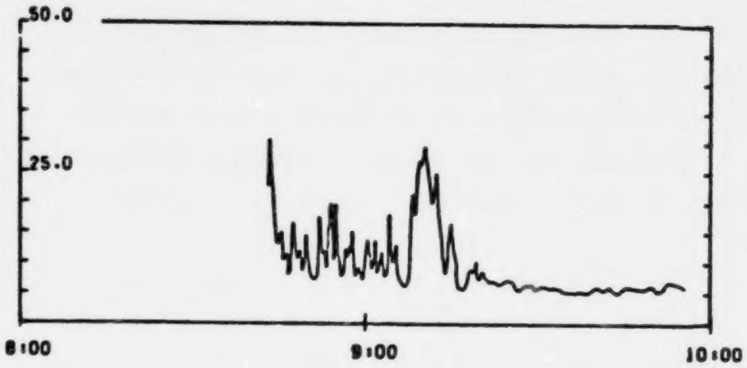
The Study was set up with continuous monitoring instruments for species like carbon monoxide, nitrogen oxide, nitrogen dioxide and batch type samplers for formaldehyde, aldehyde and the odorant species. Our studies on diesel exhaust odor have led us to collect things that we call aromatics which are the heavy aromatics, like the aromatics in diesel fuel, and the partial combustion products of that same volatility range of materials called the oxygenates on chromosorb 102.

#5 Typically the instrument patterns looked about like this trace for carbon monoxide. They showed escursions ranging about 10 to 1 over the concentration range, for any given species we were observing. The distribution of concentrations calculated are shown in the next series of graphs for several of the easier species, the ones that can be recorded on continuous monitors.

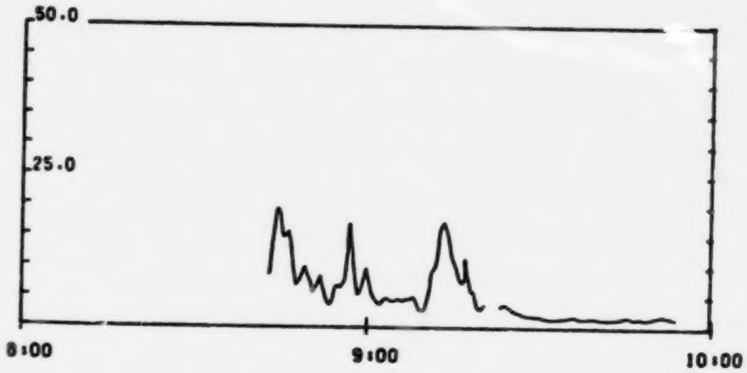
#6 This is the carbon monoxide distribution data which shows that 90 percent of our data was found less than 2 parts per million of carbon monoxide. There were only a few excursions, 1 percent at a time did we get up in the 15 to 50 parts per million carbon monoxide concentration range. These are the plots of the average values -- in fact, the only time we exceeded either the projected new 35 parts per million carbon monoxide standard or the existing 50 parts per million carbon monoxide standard was the time when the teletram backed into our instruments and dumped the exhaust directly in.

#7 This is the same sort of plot for the nitrogen oxide, nitric oxide. In the mine we find that 90 percent of the values are about 1/2 part per million.

#8 The nitrogen dioxide values on the next chart are quite



Instrument A



Instrument B

Figure V-7. Carbon Monoxide Concentration (parts per million) at Two Locations Near the Working Face vs Time of Day (See Figures V-8 and V-9 for Sampling Locations.)

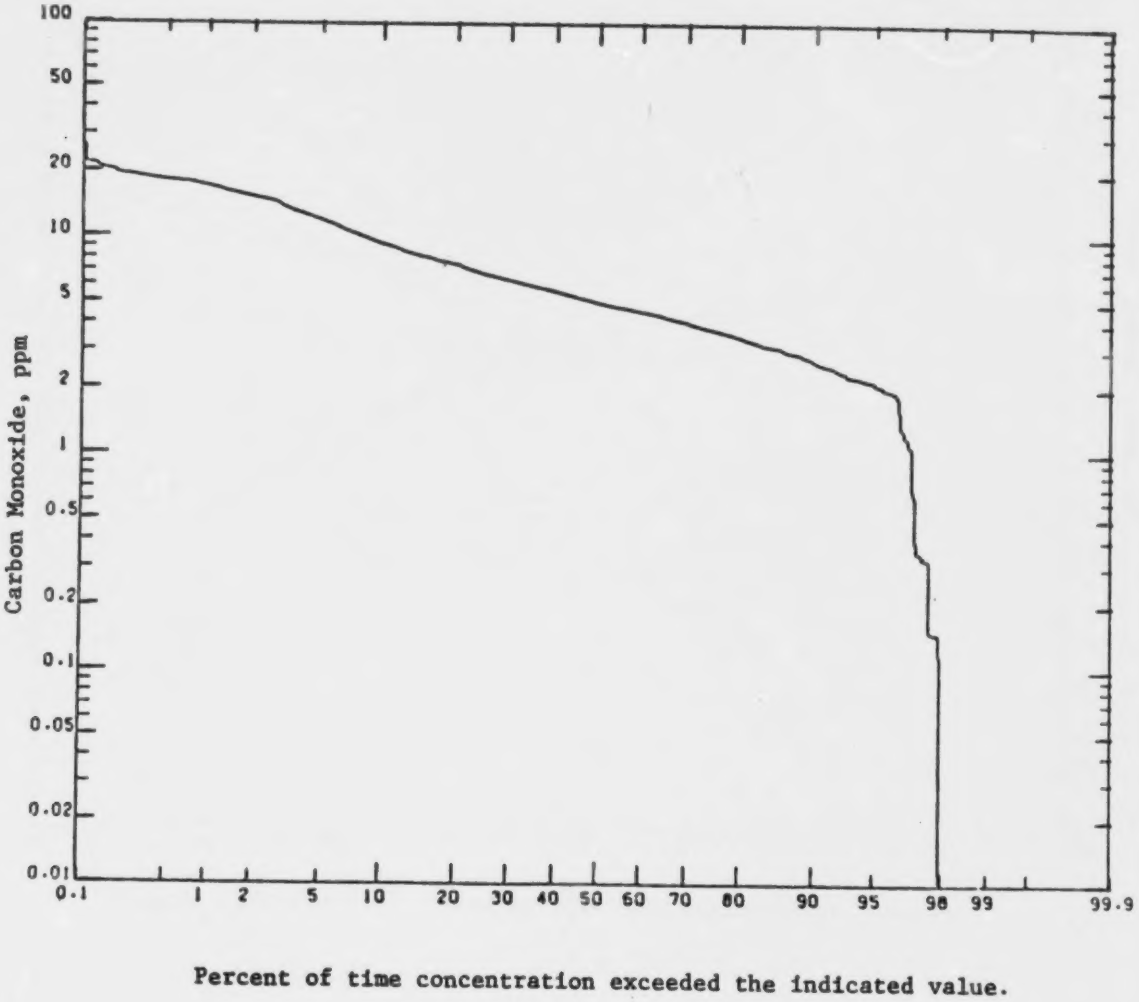


Figure V-1. **Cumulative Frequency Distribution of Carbon Monoxide Concentration Measurements in the Return Air Passages of the 002 Section**

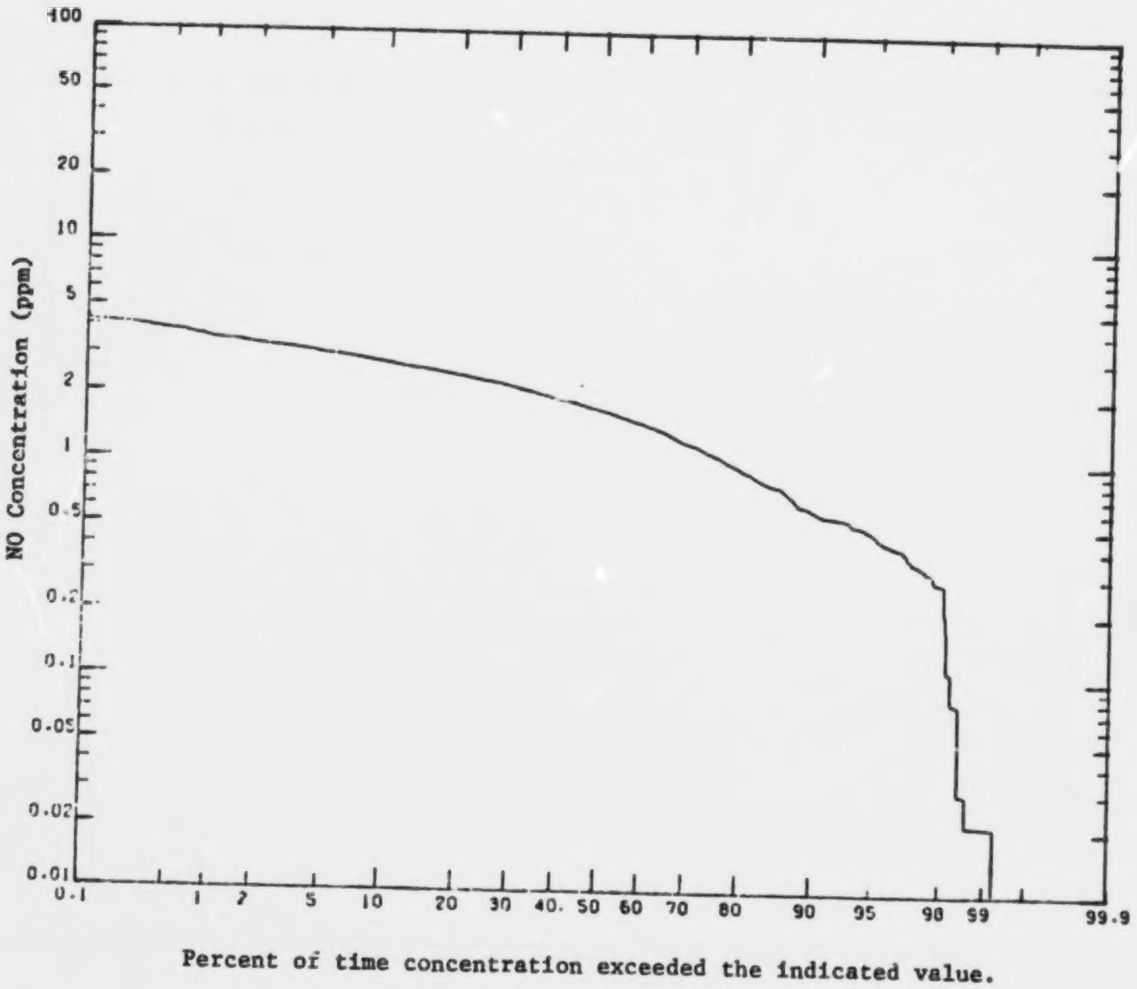


Figure V-11. Cumulative Frequency Distribution of Nitric Oxide Concentration Measurements made in the Return Air Passages of the 002 Section.

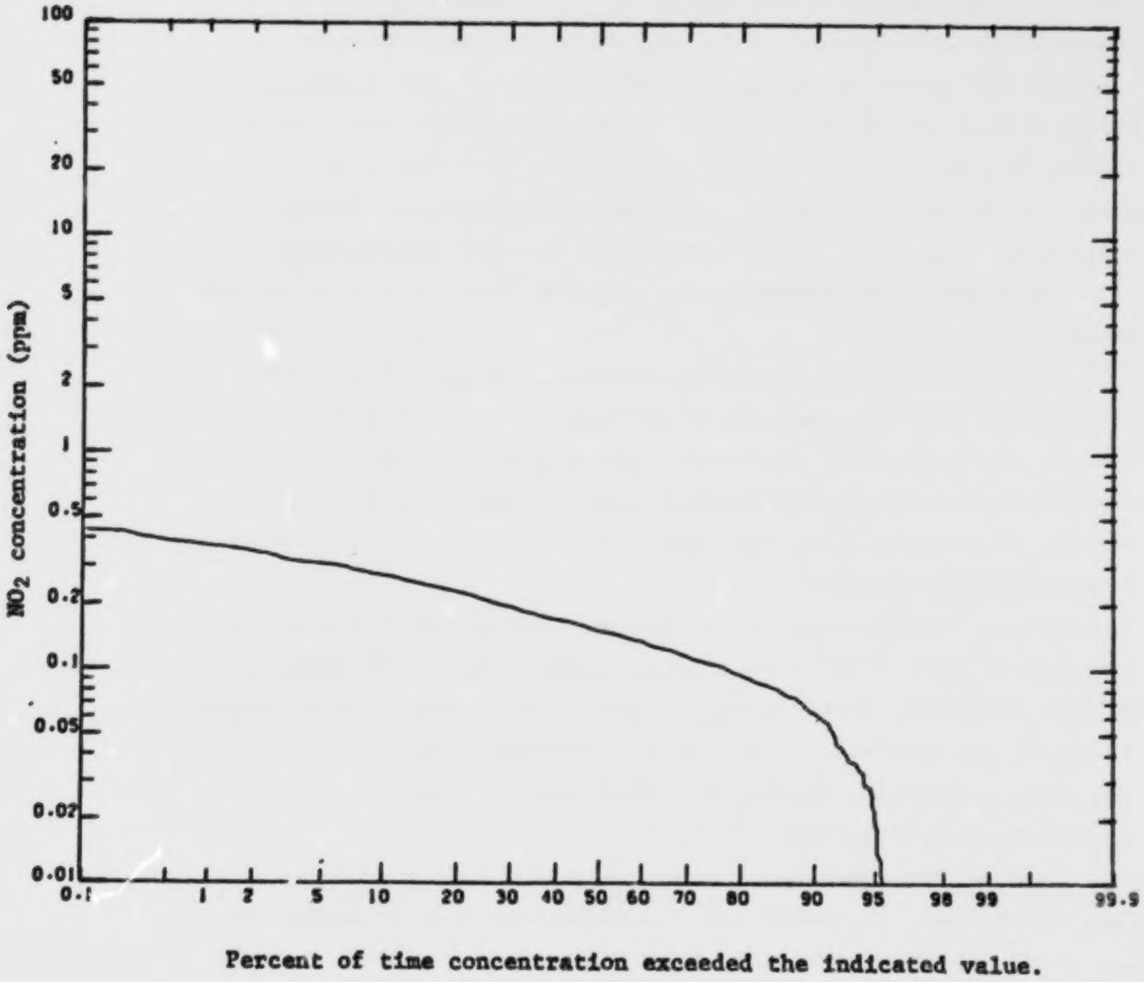


Figure V-14. Cumulative Frequency Distribution of Nitrogen Dioxide Concentration Measurements Made in the Return Air Passages of the 002 Section.

comparable but down by a factor of 10. Ninety percent of the time there was less than .05 parts per million of NO2, and, similarly, maximum excursion got up to about .4, .5 parts per million of nitrogen dioxide.

This last table has a lot of information on it. #9

Let me run down these a bit at a time. There are two key pieces of information on the chart. For the species, groups of compounds that we measured there are the mean concentrations observed during the entire set of experiments and some appropriate health associated values. These are threshold limit values set by the ACGIH group. They are quite comparable, with some minor exceptions, to the MHSA values for coal mine environment, or mining environments generally, and they are essentially the OSHA standards as well. It is more of a time reference than anything else for the difference between these.

These values represent concentrations and appropriate units, either milligrams per cubic meter or parts per million for the speices, for the most part on an eight-hour time weighted average value. There are a few key species, formaldehyde and nitrogen dioxide that have ceiling values associated with them. It is usually taken to be about a 15-minute measurement.

Carbon monoxide mean value observed during the entire set of experiments about 7 parts per million compared to its 50 parts per million standard. Nitric oxide at about 3 parts per million compare to its 25 ppm standard. Nitrogen dioxide about a factor of 10 down, .34 parts per million against a 5 ppm standard. That standard is in a state of flux right now.

Some of the other key species, some that have been dealt with more in the past are things like the aldehydes, both formaldehyde and total aldehydes here being about .05 parts per million. It is hard to know what to use as a health effects standard base to compare it with.

Table I-1

Comparison of Personal Sample Data with the Threshold Limit Values

Species	Concentration Units	Measured Concentrations			Threshold Limit Value
		Lowest	Mean	Highest	
Aldehydes	mg/m^3	0.004	0.045	0.19	3* - formaldehyde 180 - acetaldehyde 0.25 - acrolein
Aromatic Hydrocarbons	mg/m^3	0.13	0.69	2.1	50 - napthalene
Carbon Dioxide	ppm	450	650	1150	5000
Carbon Monoxide	ppm	1.5	7.6	14	50
Formaldehyde **	mg/m^3	0.007	0.038	0.059	3*
Nitric Oxide	ppm	1	3	5	25
Nitrogen Dioxide	ppm	0.10	0.34	0.47	5*
Oxygenates	mg/m^3	0.006	0.039	0.11	19 - phenol 22 - cresol (all isomers)

* Ceiling Value

** Estimated from the average NO/NO_2 ratio (10 to 1) obtained with direct reading instruments.

What we have done in this case and a couple of the others is take a worst case assumption. If it were all the species for which there is the lowest health effects standard then how does that compare? In the case of species for which TLV values have been set, acrolein has the lowest value. Its standard in milligrams per cubic meter is about 0.25. That is 0.1 ppm. That is about a factor of 5 greater than the actual aldehyde concentration measured.

The aldehyde values includes all of the aldehydes from the exhausts that are found in the ambient air after disperison; if it also includes then, for instance acetaldehyde and formaldehyde you can see that the values observed here are well below any of these appropriate standards; even the highest excursion here is still well within that kind of range.

The formaldehyde value itself is about still in that same kind of order, .04 compared to the 3 milligram standard for formaldehyde.

The aromatic hydrocarbons and oxygenates are really the groups of things that come out of the odor effects tudies. In addition to the instrumental and chemical analysis studies that we did in this program a team of trained odor analysts went down along in the mine as well and made a series of observations.

The aromatic hydrocarbons for the most part have a composition about like the diesel fuel aromatics. In this particular mine they were using a number one fuel. The aromatics are dominated then by the napthalene series, for instance. The TLV's for the aromatics are all on the order of 50 milligrams per cubic meter which is the specific value for napthalene in this case. You can see we are well within that kind of range.

The oxygenates are the partial combustion products of a whole bunch of chemicals. They are the group of species that are primarily responsible for the characteristic odor of diesel exhaust. The mean value of the concentrations observed for these species was about .04 milligrams per cubic meter. This is a particularly tough group to deal with from a health effects point of view because it is such a complex mixture. There are by rough estimates maybe 1000-2000 specific compounds.

The dominant chemical species, not the dominant odor speices, but the dominant chemical species in this group are the series of alcohols, being phenols, cresols, the benzene alcohols, the napthalene alcohols -- and there are the TLV values for these fellows for phenol and cresol in particular. Those TLV values are quite high, about 20 milligrams per cubic meter, and we are well below anything like that kind of level. So from an appropriate standards point of view there does not seem to be any particular problem associated with the oxygenates there. Those fellows do smell, and they are readily observable in the mine.

In addition, there are species in the oxygenates group which are known to be irritants, like the phenol for instance. I th think that a simple comparison of numbers like this doesn't tell the whole story about what the potential health effects of this group in particular is in any kind of environment.

Rembmber now that this data represents about 100 to 1 dilution of exhaust in this environment. That is a number not unlike what you will get on curb stop in an urban area; dilution estimates vary between 100 to 1 to 1000 to 1 for that kind of environment. It represents a fairly nice, if you don't mind working in a five-foot ceiling or four-foot ceiling in the mudy, aanice environment in which to control your dilution at 100 to 1 and be able to collect data under some variable conditions to see what these concentrations really are like.

The odor studies that we did down there are interesting. For the most part in the majority of the environment of the mine there was no detectable diesel exhaust odor. The diesel exhaust odor was readily observed anywhere close to the environment of the equipment, but the roof bolters, for instance, that are usually working a room or two away from the working face did not have any exposure to diesel exhaust as perceived by the odor observation.

In the environment of the working face or the teletram equipment, the conveyor belt, places where the teletrams were idling or loading up, the diesel exhaust odor was readily perceived. It was in a medium intensity range. Our scale (TIA) for describing that goes from slight to moderate to strong, moderate being about in the middle of the D scale. The odor observations that environment were generally in the slight to moderate kind of range. That is 1 to 2 on our TIA scale of 0 to 3, and it is about 2 to 4 in the D scale, so that the diesel exhaust odor is readily perceived in the immediate environment, but any distance removed from that like one room away, about 40 feet, there really was no perceptible diesel exhaust odor.

The net conclusions out of these observations was that, as it applies to the mine environment, the diesel engine really represents some significant advantages in terms of all the factors that have been put forward for productivity, safety which is a plus minus question at the moment, but from the chemical concentration of toxic species point of view we seem to be well within any recognized standards. That is not to say that we are not going to recognize that some of these standards ought to be lower in the near future, too, and that is another kind of problem, but there is such a significant margin in many of these cases there does not seem to be any significant problem.

We did note some particularly interesting deviations from this typical 100 to 1 dilution up here. The aromatic hydrocarbons, this was the mean value, on the average it represents a dilution something less than 100 to 1. We have taken to interpret that as being hydrocarbons contributed from the mine environment itself, especially in the area of the working face where fresh surfaces are being exposed constantly resulting in emissions at these kind of concentration levels. We are not talking about very much here and these could be readily expected.

The other effect was that the odor intensity observed by the human panel in this instance was typically lower than that which we would project from this kind of concentration number. We did observe that the water spray flame trap on this equipment had a significant effect in the way that the odor, especially, was emitted from the engine and some speculation that a good bunch of this stuff gets caught up in the aerosol that comes out of the water cooler and therefore is in particulate form or aerosol form rathern than the gas form which it normally is in from diesel exhaust. This would lead to a different set of observations by the odor panel and by the methodology which we use to collect and analyze these samples. That is another kind of problem area to work on again in the future.

As I said, this is just a quick summary of the data. All of the data is available in a final report from the Bureau if you want to request it.

I would be happy to discuss any of the details of this with anyone who is interested.

Thank you.

MR. GROBECKER: Thank you very much, Mr. Levins.

The next speaker is a visitor from England, Richard Wheeler of Ricardo who will give a paper on "Human Impact of Particulates from Different Sources."

MR. WHEELER: I want to make a few remarks just to tell you a little about what is going on in Europe, in Britain in particular. There has been quite a lot of activity in this field of the human effects of diesels mostly in a fairly practical arena.

The British Occupational Health Society which is our version, I imagine, of NIOSH has set up a committee which is under the Medical Research Council's Environmental Hazards Chief who you perhaps are familiar with, Professor Pat Lawther who GM have had some contact with, and who are putting into their report on this meeting some results which he has been getting. So, I won't say any more about that, but this particular committee is also under Pat Lawther, and it is to look at problems which have arisen in factories, loading bays and occupational areas in general with problems with the unions and with other people which have arisen from the use of diesel vehicles.

A typical instance is where a large truck backs into a loading bay and then there is some time during which the truck is left idling when perhaps the driver is signing up some forms for the person in charge of this bay. Five minutes can go by, and then the truck driver gets back in, puts his foot on it and moves off. This puts out a large cloud of blue fume which has caused work stoppage in some areas in large factories.

The original problem arose from a large company in its spare parts depots. It is really a serious problem. We tried to get some view of what we could do about this. How could we let factory managers know what was the tolerable level of diesel exhaust? How many diesel engines could run for how long and produce how much power for what time in a given space with a given degree of ventilation?

Well, for one thing we really don't know exactly what these people are complaining about. They just say that it is the stink of the thing. Well, Phil Levins has done quite a lot about one part of that stink, about the odor, but stink and odor are in the English language not exactly the same.

We believe ourselves on this committee that it is probably total particulates which these people are complaining of, also they are objecting to being enveloped in a cloud. They are objecting to the odor of it because this frankly makes a lot of people sick. It does not make me sick, but then I have worked in it for about 30 years. I know roughly what it is, but an ordinary person who does not even know roughly what it is tends to have an instinctive feeling of revulsion against it.

This is a fact of life and it is a problem in many areas of industry. Loading bays, for instance, at large airports where they use forklift trucks, all sorts of problems have arisen with the operation of diesel engines in these. Attempts to put catalysts on them have really failed because they have used straightforward gasoline car technology and hung a catalyst in the exhaust line. Inevitably it has been too cold and has not catalyzed and has clogged up and almost stopped the engine making it smoke even worse than usual. So that has not really been the solution. At this moment we are addressing ourselves to this problem. It is a serious one for industry, and it is the sort of thing that in the streets in Britain we have grown along with, and we tolerate it, at least some people tolerate it.

Well, that is a bad thing about the diesel when it is operated under those conditions. There is no suggestion this is a badly maintained diesel. It just happens that if you run at idle for any length of time that the hydrocarbons collect in the exhaust pipe. The moment you put some hot exhaust through it they boil off in a large amount. So, it is not something that we see too much in our our type testing procedures.

So, that is one problem which we have got to look at because it is somewhat wrapped up in the cold start problem when one has quite a number of diesels together in one place where perhaps the ventilation is bad.

At Ricardo sometime ago we wondered whether in fact this was entirely a diesel problem. We don't believe it is because we believe that the ordinary gasoline engine if it was used in these types of situations would also cause considerable trouble. In Britain it cannot because there just aren't many in this area. In fact, the airport loading forklift trucks probably would not have petrol engines. They would be propane or diesel. Propane engines generally don't give much trouble at all, but if there were gasolines in this area we feel it would equally be as much trouble unless of course they had platinum catalysts.

Maybe you would not be enveloped in quite such a blue fog, but the stink would if anything be worse. So, we did some work on the particulates related to these various units and under the type of wear that you might get. Now, remember in the States you are going to smaller cars. We have already got them. Your big engines just do not wear except under very exceptional circumstances. Now, small European cars that are driven very hard and also many cold starts do wear. They get a lot of bore wear and they develop a lot of oil mist, and a lot of oily particulates.

Now, another thing which makes oily particulates are two-stroke motor bikes of which we have a lot. In certain parts of Europe there are almost as many of these as there are gasoline cars. Amsterdam is a particular example, and in Amsterdam, the T.N.O. organization has shown that a 50 cc petrol lubricated Moped gives something like ten times as much PNA material as a 2-liter gasoline car. This is a normal stoichiometric European 2 liter. So, in terms of the PNA's in Amsterdam it is very likely that it is Mopeds which are the cause of the trouble.

Now, I believe you are going to get even more Mopeds over here. The 2-stroke petrol lubricated machine is really a bad one, for particulates.

Figure 1 shows the extent of the problem as we have measured it on worn cars and worn diesels. #1

The top bar is a new 1.6 liter gasoline vehicle, and the particulates are about .03 gm/ml. The next is an old 1.6 liter vehicle that has done a lot of stop-start, short distance operation over 75,000 miles with a new oil in it, and it has got about .25 grams per mile and that will be on leaded fuel.

So that is quite a large amount of particulates,and also, notice that when we come to the new diesel 2-liter we are getting values of only about .4 for a good one. Any of the 2-liter ones will give about .4 with a reasonably well adjusted injection system.

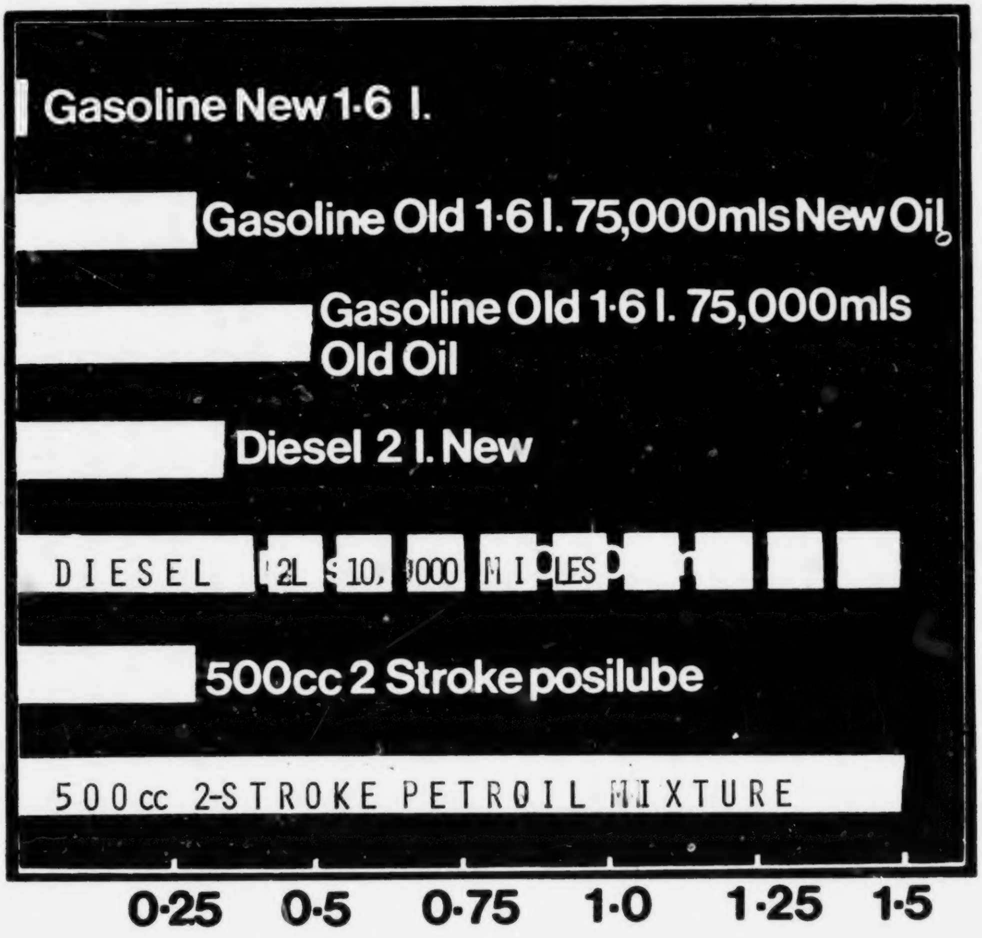
Remember that most of the diesel particulate is, in fact, soot. So, the hydrocarbon material is perhaps only .05 gm/ml, whereas almost all of the gasoline particulate is hydrocarbonaceous material. How does it get through the combustion system? This is something we know very, very little about. How do oil droplets get from the top ring out through the exhaust valve and how are they pyrolyzed and what amount of carcinogenic material is produced on its way. We just don't know. The work has never been done. All we have done is to look at some old and new vehicles to define the limits of the problem.

The third bar is for the same worn gasoline vehicle here, but it has old oil which is completely additive depleted. In other words, the viscostatic and other additives are no longer working, and the oil is therefore effectively a much thinner oil. It escapes past the rings more readily. A bar chart whown below gives this in more detail.

The fifth bar is for a well known diesel engine of 2 litres after a high mileage of average private user stop-start operation.

Now, our friends at GM have told us that their Olds has very good durability, but that is probably a well-regulated vehicle run under proper factory type conditions. This particular one was run under very typical rough and ready conditions. Possibly

Ballpark Particulate Levels
Gm/ml F T P.



RICARDO

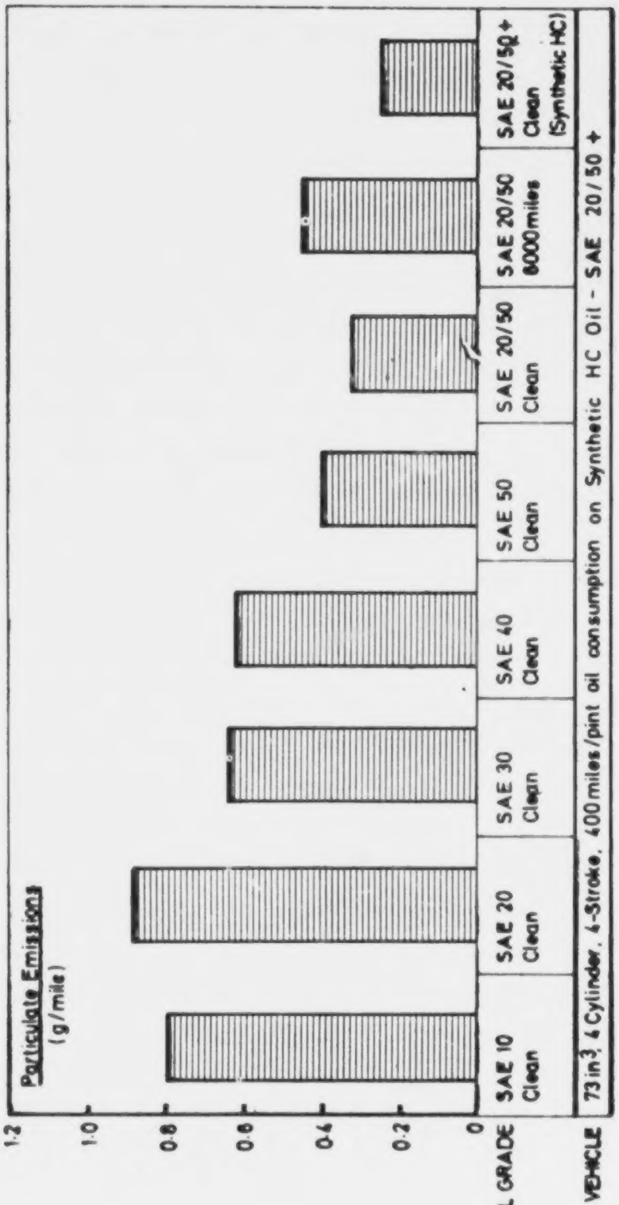
the oil has never been changed quite as frequently as it should have been, and we have gone right out to nearly 1.5 gm/ml with an ordinary 2 liter, and one does not have a black cloud of smoke. It only has a very faint blue plume when it is running. You have to look hard. Even the police would not object to it. So, that is what you could get with a worn diesel if, in fact, things went very bad with it.

The final bars are for well known 2-strokes which we have measured ourselves. The first is a 500 cc two stroke twin with a positive lubrication system which means that the oil is not in the petrol. It was really quite creditable. It gave only about 0.25 gram per mile which is reasonably good in comparison with these others, but remember maybe something in this lub oil contributes towards the carcinogens which the Dutch authorities have seen, and this is something perhaps oil formulators need to look at, whether certain oil formulations do, when pyrolyzed lead to more PNA's than others. I am not sure whether any of this work has ever been done.

Again, a smiliar two stroke which had petroil lubrication gave a large amount of 1.5 gm/ml and that is a new, not a worn engine.

Figure 2 gives some figures on the sort of particulate changes you can get with different lub oils in the same engine. It was done using a particulate tunnel test on the engine with a particular lub oil in it. We then changed the lub oil, ran the car for a while, changed the next test lub oil, ran it for a bit longer, until we got it used to that lub oil. When it was spread all around the engine we did another particulate test. The test vehicle was a small 1250 cc four cylinder, the orthodox OHV car with a fairly worn engine. #2

We did the tests so that there was no wear or any change that we could avoid in the engine system while this was happening. The first one was an SAE 10 completely non-additive oil. Now, we see that the particulate is a little bit less than on the SAE 20. With the SAE 20 it has actually got more particulate because the SAE 10 burns in the combustion. The total particulate reduces steadily from SAE 20 to SAE 50 straight oils.


Particulate Emissions
(g/mile)
1.2
1.0
0.8
0.6
0.4
0.2
0
OIL GRADE
SAE 10 Clean
SAE 20 Clean
SAE 30 Clean
SAE 40 Clean
SAE 50 Clean
SAE 20/50 Clean
SAE 20/50 8000 miles
SAE 20/50+ Clean (Synthetic HC)
VEHICLE
73 in³ 4 Cylinder, 4-Stroke, 400 miles/pint oil consumption on Synthetic HC Oil - SAE 20/50 +

When we go to a 20/59 formulation, we get another advantage. Then we used the same 20/50 oil which we extracted from some of our company cars after they were at the 6000 mile oil change level, and you can see that the 6000 mile oil change has put the particulates up by something like 50 percent.

Here then is a problem of oil formulations and particulates. Then, again, if you use a synthetic hydrocarbon oil, in fact, it was Mobil SHC because it had local suppliers, and that gave the best result of all. So, here is another thing that we should be looking at. We are looking at, I believe, quite urgently the effect on fuel consumption of oils. We should be looking at the effect of oils on particulates and on the carcinogenic material within these particulates.

Well, what are we going to do about all of this? Remember that what is upsetting people and contributing to people's possible ill health is not new 'type test' vehicles coming from factories, it is half worn-out vehicles that are going to be the major contributors. We need to have a lot more data on the wear of vehicles, the particulate life of vehicles, particularly of diesels. In user operation there is no way we can get this in less than about five years, as I see it, and as far as I can see nobody has even started this work. So, bearing in mind that the U.S. is going to a larger population of small cars, what is the wear of these going to be? It will take five years to find that out. What is the wear of the diesels which you are going to make going to be in your typical American user? Already the General Motors people have been quite frank about the problems of lub oil in diesels. It is a problem. It does deteriorate quicker than in gasolines, and it is a thing that has to be thought of. This type of work is not even, as far as I know, contemplated. So, I think it is urgent that it should be looked at, and I am going to offer now a suggestion as to how we can get a quick answer.

Now, I am going to make the suggestion that all this can be looked at in one large laboratory, and there is a large laboratory, and it is London. There is a good deal of statistics in London on the traffic flow. The London County Council has a tremendous amount of data on traffic flow in various situations. Any further information can be generated very readily. I am quite sure that Professor Lawther would be only too delighted to lay on some experiments to look at total particulate samples from various areas where the traffic flow could be looked at. We would then have a user fleets of vehicles, diesels, petrols and I think possibly in the middle of London there would not be this awkward factor of the motorcycles. It would really not be appreciable. They hardly survive in the middle of London.

So, we really would have the ability to know how many diesels and how many gasolines were going up the streets. It would not be very difficult to generate some average information on the particulate levels of the two fleets by selection of used cars. A statistician could easily work out a system for doing that. It would not be difficult, and I am sure the British Government would be quite keen to cooperate in something of this sort. It is a laboratory. You might very well have something like London in perhaps 15 years' time. So, I think I am sure I could speak for the authorities that they would be quite cooperative in this.

I am sure Professor Lawther would be because I have already spoken to him about it; however, if any of you are interested to follow this up, I could talk to them afterwards.

Thank you very much.

MR. GROBECKER: Thank you very much.

Our agenda now calls for a panel discussion. By that, I suggest that representatives or spokesmen for today's papers join me here to respond to questions which you may ask them.

Is Mr. Klimisch here?

MR. HEUSS: I will represent Mr. Klimisch.

MR. GROBECKER: All right, Mr. Heuss for General Motors, and Mr. Winter of the University of California, and Joe Sturm of Transportation Systems Center, Mr. Wheeler of Ricardo, Philip Levins of Arthur D. Little, and Dick Briceland of EPA.

Since the people at the front table have all had their chance to speak, perhaps there is another spokesman, someone who will volunteer the first question to be addressed to the panel.

Would you tell us your name, please?

MR. FRIBERG: I am Norm Friberg. I am with Volvo of America. I would like to ask a couple of quick questions to clarify a certain point. I believe it was Mr. Levins talking about the condition of the air in the mines. You were giving some concentrations in terms of milligrams per cubic meter. I wonder if that might have been micrograms. Is that true?

MR. LEVINS: No, sir. Those were all milligram units.

MR. FRIBERG: The other question was, and I hope I am not mispronouncing it, Mr. Van Cauwenberghe? I would like to ask if he had any feelings regarding the fact that the BaP emitted from diesel engines is largely adsorbed to carbonaceous particles and whether he had any feelings as to how this would affect the mutagenicity as opposed to the laboratory studies where the BaP was kind of on its own?

DR. WINER: I will speak to that, since I am from that laboratory. There is a need to look at various substrates in these experiments and particularly ones more nearly simulating diesel particles themselves. We intend to do this. We have some indication that there are effects associated with different substrates, but we want to look at a hierarchy of experiments beginning with the type of filter experiments that were desdribed earlier. Then going to the possibility of coating materials onto particles and ultimately, of course, to chamber experiments in which you would like to study the particulate in an in situ type of experiment. That is in a simulated smoggy atmosphere where one could try to follow what is happening under conditions that are very closely approaching those in the atmosphere. There is a need for a program to do this in a very systematic way. We hope to carry out such a program.

MR. VOSTAL: Vostal, GM Research Laboratories. I would like to continue on the same tune and to ask the question either to Dr. Winer or to Dr. Van Cauwenberghe, particularly two questions. When I have heard the presentation by Dr. Pitts yesterday and, also, the beginning of the presentation of Dr. Van Cauwenberghe today, I became a little too scared, and I wanted to ask the first very important question. Does it mean that, since you have discovered that there is a filter effect that all the data that we have collected up to now using filter techniques should be questioned, that we should really go back and repeat all of our experiments? I have been little consoled when I have seen that what we did not see yesterday from the presentation by Dr. Pitts that you have to use concentrations as high as 10 ppm of ozone to get an oxidation done, what a small amount of the microsomal fraction could do for you without any problems, and also that you need at least 24 hours before 1 ppm of nitrogen dioxide will generate a yield of about 10 or 12 percent of the nitrobenzanthracenes.

Now, I would like if you share the same opinion with me or if you could really tell us how much is the impact of your studies in this area? My second question is a little more serious, and it is about the presentation of the data, particularly in the last but one slide that we have seen today. We have been told that the nitro derivatives of the benzo-a-pyrene are moderate mutagens and it has been documented by some plots of the dose response curve. Now, if I remember it correctly in the case of the 1 and 3 derivative which has been there, I have not seen without the activation any higher numbers of revertants than something around 100. Is this correct, using the TA 100 strain? Now, I am not an expert in the field of the Ames test, but just based on our own experience, we have to be aware that the TA 100 and TA 98 strains are very sensitive, and they are having a considerable level of the spontaneous mutations, and sometimes we are getting levels as high as 90 or 100 even in the blank experiments.

Moreover, whenever you look at the criteria and guidelines which have been recommended either by a special science advisory panel created by EPA or by the Mutagenic Society, and correct me please if I am wrong, we should never talk about a positive mutagenic effect unless we have seen it on at least two different strains of the Salmonella. We should never declare a mutagenic effect unless we have observed in two successive steps of our dose response curve at least a redoubling of the original effect with the low dose. I think that these criteria have not been satisfied in your data presented on the direct activity of the nitrobenzanthracene, and it is further confirmed that you have seen a tremendous enhancement of the mutagenic effect by activation.

Practically, in my mind they are still identical data, what you can see after you have tested benzo-a-pyrene alone; and the nitro derivatives did not differ from it so much.

MR. GROBECKER: Mr. Winer, do you choose to answer those two questions? Please repeat the question.

DR. WINER: I will answer the first question, and then I would like to ask Dr. Van Cauwenberghe if he would respond to the second one.

The first question dealt with the serious problem of whether or not the air monitoring data base could be in jeopardy because of the sort of effects that we are seeing on filters. We feel this is of considerable concern.

I think your representation of the exposure data was not quite right. In the case of 1 ppm NO_2 with traces of HNO_3, for example, we see reaction rates that are very appreciable on the time scale of hours. Not just a 24-hour exposure but on the time scale of, let us say, four to eight hours. We find yields up to 50% depending on the coating procedure. We are about to carry out experiments in which the dose is lowered to something a little bit more representative of the usual ambient levels of NO_2, although, I am sorry to say, that in the South Coast Air Basin, at times we approach the 1 ppm level in the coastal cities. But we would like to look at levels of, for example, .25 ppm; and we believe we will see appreciable conversion rates on time scales corresponding to an irradiation day, that is, 10 to 12 hours.

So, we do feel this is going to have to be taken into account in trying to assess the validity of previous data, just as the technical community is undertaking a very serious look now at the nitrate artifact problem in terms of the air monitoring data base.

The answer then is, in our simulated atmospheres, we have observed significant effects on filters which, perhaps, may occur in ambient air. If so, this has major implications. Much more data are needed to say how good those past data are and to what extent we have to worry about this in the future.

Karel, could you first define what the second question was, and then try to address it?

DR. VAN CAUWENBERGHE: I thought the second question was about the validity of the mutagenicity data we have obtained for these nitro BaP derivatives.

First, I would like to point out that any mutagenicity test conducted in our microbiology group is done with all five strains. So this was done for these nitro-PAH compounds. Of course, it is true that the backgrounds for the strain TA 100 are somewhat higher than for all the other strains. However, I should emphasize that all reported data have had the backgrounds subtracted. The result that we obtained by normalizing a response to, let us say, microgram of compound or nanomole of compound may appear to be low; but other researchers have obtained dose response curves for these compounds which they consider to be typical of strong mutagens.

MR. VOSTAL: If I did not express myself clearly before, then I would like to try to clarify my concerns now by a simple question. All that you have said is that you have proved that you have seen a direct mutagenic effect with nitro derivatives of benzo-a-pyrene. Now, if you classify what we have seen on the slide as proof of the direct mutagenic effect, I would like to question your conclusion; but, again, it will probably be better that this should be discussed in front of an audience which is composed of people directly involved in this business of bioassays instead of discussing it here.

DR. WINER: Could I just add one more thing? First of all, the major point that we are trying to make with these data is that we have strong evidence for the chemical transformation of certain PAH, in particular, the production of species like nitro compounds, hydroxyl compounds, and so forth. That is really the chief accomplishment here. The question of the degree of mutagenicity or the ultimate carcinogenicity of the spectrum of products that we are seeing from the chemical transformations of PAH is something that requires, obviously, a great deal of quantitative study. This was stressed by Dr. Pitts yesterday.

Our concern is that, if you are looking at the potential impact of the PAH's, you now have to take into account that the dose part of this is going to depend on where you are in an air trajectory. That is, where you are in the history of the chemical evolution of the PAH's through nitro compounds, other intermediates, and ultimately to the quinones. So, the bottom line is that you must now be concerned with these chemical transformations; and then, of course, you have to assess the biological implications of that spectrum of compounds that you are seeing.

MR. LEVINS: I would like to pick up on the particulate question that was raised, if I might, before we lose that point.

It is not clear to me what impact the work at UC has on the validity of the data base from ambient air studies or from gasoline exhaust studies on PAH concentrations; but it is clear, in my mind anyway, and I don't know how many of you share it, that the PAH data that we have from diesel exhaust has some serious reservations about it anyway.

There is an abundant amount of data now that says that under the conditions normally used for PAH particulate, there could be significant problems. Reaction conditions are optimum; and evidence shows substantial losses of PAH, under controlled experiments using things like radioactive labels, for instance. So, I think the data base that is available there is really very questionable, very shakey, when you have to use correction factors in the order of hundreds to get back to an original exhaust concentrationllevel; and some new methodology is really needed to obtain reliable data, certainly under diesel exhaust conditions.

MR. HAFELE: Joseph Hafele, Caterpillar. I came to this meeting confused, and now I am even more confused because I thought I was beginning to understand this anomalously high response that the Ames test has for the particulates from diesels on the grounds that it is the oxygenated materials in the particulate which is causing the large response, larger than what can be accounted for by the benzo-a-pyrene. I have read a recent article in Science where I believe a group from Newfoundland reported Ames tests on used crankcase oil. They found that fresh fuels and crudes did not cause a positive response with the Ames test and, therefore, concluded it to be non-mutagenic. However, they found a negative response with used crankcase oil. They were raising a flag saying that we should, perhaps, be worried about where we put used crankcase oils. That would be in agreement then with the idea that it is the partially oxygenated, or the so-called "half burned fuel", which is the problem. I have not heard much about that.

I had previously come to an understanding that half-burned fuel might be the problem. Now, I hear that it is the nitrated benzo-a-pyrene which may be a problem.

I have one question in particular, and a second in general. If Phil Levins could explain a little more of what the fraction of this oxygenate he talked about was in the total particulate fraction. Is it a large fraction or a small fraction? I would like to see, also, some discussion of the relationship with half-burned fuel to the problem. Is it known what is causing the 100 to 1000 times increase in response in the Ames test?

MR. GROBECKER: Mr. Levins, please. Describe each question as you answer it.

MR. LEVINS: Let me respond to the question of the matter of composition and abundance and stuff, and a point that I did not really make during my presentation. In the coal mine environment, I am not about to try to sample particulate and try to make any sense out of it in terms of attributing contributions to the natural environment, the ambien air environment that is sucked in in the intake air and the percent contributed by diesel engines. That is a really sticky question. Clearly, as far as the overall particulate burden in the mine is concerned, you can shut all the diesels off and you hardly ever notice the impact.

Generally, speaking, that oxygenate fraction that we measure has constituted, say, 1 to 3 percent of the soluble organics from diesel exhaust. That is not necessarily the same soluble organics that are extracted from particulate. For the most part, there is some portion of the higher molecular weight organics that are emitted from diesel engines that are condensed on particulates and collected as the soluble fraction.

So, I don't know what percentage it might represent of that. In my mind neither of us wants to tackle the harder part of your question about the mutagenic effects on the chemistry and stuff. In my mind the UC data points out, finally, for most of the community to recognize that PAH question is a very complicated one. The whole toxicity question is a complicated one and, simply, that there is a realm of chemistry going on and a realm of reactions going on both during the collection process and after, that we have suddenly recognized. When we get to interpret all the way you would like to, we will all be happy, I am sure.

In the oxygenate fraction that we collect and analyze, if you run an infrared spectrum of it, the predominant features that you observe are a nitro band and carboxylic acid band, for instance. So, nitro shows up as a very large feature of that part of the chemistry as well, although it has never been a part of the chemistry that seems to acoount for anything, like oddors for instance.

MR. GROBECKER: The second question had to do with half-burned fuel.

MR. HEUSS: I will just suggest that that question be asked of the panel this afternoon who are health experts and experts in that sort of testing. I don't think any of us have any background in that.

MR. CROWLEY: Jim Crowley from Battelle, Columbus. I regard the second question as flag waving about a certain class of compounds. I think we must always remember it was mutagenic in that system and non-mutagenic or mutagenic in that particular test system which seems like a trivial statement but an extremely important point, which I am going to address a little bit this afternoon.

MR. LIES: I am Karl Lies from VW. I have a question to Mr. Wheeler. How many tests did you run in your investigation studying the dependency of the particulates from the oil used? It is well known that the spread of results from repeated tests is very high, and if you have run only one test with each oil, it is impossible to draw any conclusions from that.

MR. WHEELER: Yes, I quite agree that one cannot draw very hard and fast conclusions. We could only do one test for that in that situation because with a worn engine of that sort, if you test over a very long period, you will automatically get drifts. We tried to avoid this by doing one test and then moving to the next one before the engine shifted in any way. I quite agree, it is very difficult; but I was really pointing out that there are questions to be asked her and that we, perhaps, could answer them by investigating in the London atmosphere using high volume samples.

Perhaps we could show from a given population of cars, how much of the high volume sampled material was gasoline car derived and how much was diesel derived, and we would have to think very hard how we did this. I am sure chemists could think of ways of separating out the two within the high volume sample; then, that could give us a good clue as to the particulate levels of a population of worn cars. I quite agree. It is a very, very difficult problem. I think all we showed was that there might be a case to answer.

MR. GROBECKER: Have we another question?

MR. SHUMAN: Arnold Shuman from Mercedes Benz of North America. I have another question for Mr. Wheeler. In the case of the 100,000 mile diesel that has been poorly maintained, did the proportion of carbonaceous material remain at the about 90 percent level in the exhaust?

MR. WHEELER: Unfortunately, it was done before we had our thermographometric equipment set up, and it was really done before there was much talk about this type of separation. It is a great pity, but the feeling from the look of the papers was that it was much less. Anybody who does this work can look at the filter paper and get a very good impression of whether it is just black soot or oily black soot, or oil; and these were extremely oily from this particular engine.

MR. GROBECKER: Have we another question?

MR. TOMBACH: Ivor Tombach from Aerovironment, again. Mr. Sturm, in his presentation, presented on a slide a comment which says the models introduce additional uncertainties into the whole question of assessing impacts of diesels with which I have no disagreement.

Then, during the break, one of the people here in the audience came up to me and, I think, brought up an issue which maybe I did not present quite as clearly as I should have. He said he got the impression that I had said that the modeling situation was in really good shape and that it could almost be ignored as far as an area requiring further attention.

So, I would like to clarify that point and point out that I think there is really no disagreement between any of the people who talked about modeling, be it myself, Mr. Heuss, or Mr. Sturm, that is, that when one looks at the issues related with diesel emissions and their impacts, I think, compared to many of the issues that are raised, modeling is, indeed, in good shape, particularly when you are looking at small scale, microscale effects again in comparison to the other issues. However, I think in the interest of time and economy of words, I may have given the impression that it is everywhere in good shape; and this is not the case.

In fact, I think one should be realistic and realize that there is no general purpose model in existence which can handle all, again, confining ourselves to the microscale situation which can handle all microscale situations with acceptable accuracy. Let me define acceptable accuracy and say, within a factor of 1.5 of the right answer; don't overshoot by more than 50 percent or undershoot more than 33 percent. If one considers all the possible situations, street canyons, they were mentioned for the APRAC model and I mentioned them, intersections, stop and go traffic, the topographic effects, and even confining ourselves to gases and inert pollutants alone and not even getting into the meddlesome affairs of particulate matter, particularly the larger particulate matter and reactions.

So, when one uses a model, it is important that you use a model under the conditions for which it has indeed been validated, and by validated, does not mean a 30-second test or two tests with two data points, but a comprehensive validation under a variety of conditions that indicates that the physics of the model does somewhat rationally represent what is going on. Even under these conditions, one has to be realistic and understand that the quality of the results you are going to get out of the model depends on the appropriateness of the selection of the model for the purposes intended, as well as the accuracy of the inputs; and the input data of the model sometimes can be much worse than the model itself. In fact, in most real life applications of the inputs to the model are much poorer in quality than the ability of the model to actually predict the situations, particularly in the area of emissions of real live road traffic situations. That was raised very vividly by Mr. Wheeler when he was talking about aged cars, and also with regard to the meteorology which seldom is being measured at the right location at the right time and for the right level of detail.

So, this, in summary, maybe clarifies a one-sentence comment and makes it more elaborate.

MR. GROBECKER: You are very compact. You asked the questions and also gave the answers. Thank you.

Mr. Marmo?

MR. MARMO: Thank you, Dr. Grobecker. It is fitting that I should follow. I was the gentleman to capture him in the break, an and we had quite a discussion. I am glad to hear you clarify some of that, but I did want to make a couple of comments.

I would like to say in answer to the feeling that microscale models, let us pick that, we are in good shape. I just want to say briefly that we did run a DOT-sponsored workshop with the users in the field, the very users and over 150 participants in four different parts of the country, and these were not federal people. We were not invited to participate in that sense. We asked, then, and tried to define the 10 most important issues that are bugging them in getting things off the ground, and what do you think the number one ranked issue? We ranked them. It was modeling, and their microscale modeling in all their projects, they do have plenty of situations that they have trouble with.

Now, let me say just one thing about microscale modeling. I think you are all familiar with the Clean Air Act of 1977 in which we are all worried about PSD, prevention of significant deterioration. It now deals with fixed sources. It is scheduled to deal in 1977 with mobile sources. You know, I would really like to see if Congress uses the same techniques to set those incremental differences on mobile sources that they have used on, unrealistically, the stationary sources, and that game is not over yet. I would like to see ifaanyone will get up in an audience and say, "We have the microscale modeling capability good to within 30 percent no matter what you throw at us." So, if that increment is something like 30 percent, we are in good shape.

I doubt that very much. Now, I would predict that there will be a lot of hemming and hawing when the EPA sets those standards for PSD when it comes to mobile sources;aadd just one warning remark to indicate how things change. APRAC 1 was recommended as a model today. It is absolutely rejected and is obsolete in the DOT circuit right now. APRAC 2 must be used by all users. It is not to show that the change is always coming. S So, we should be very cautious about accepting practically any models. I might finally add that the SRI San Jose model and the Phoenix models are both DOT sponsored, and I participated in monitoring on bobh of those. I think, if you were to ask the principal investigators themselves, they would not be quite as optimistic on their own findings as has been shown here today.

In brief, modeling is not in good shape; and I did not want to see us leave with that.

MR. GROBECKER: Thank you for those comments.

Am I correct? You had no questions. You were just clarifying for the record.

MR. MARMO: It is a sort of rhetorical question. I have it embedded in my PSD. Does anyone in the room think that when the PSD levels are established that anybody in the community, in the modeling community will admit that we have models that are capable of predicting the incremental levels that are going to be set by EPA? It is sort of rhetorical.

MR. GROBECKER: Does anybody want to answer that question? Mr. Tombach, would you like to anser that question?

MR. TOMBACH: I think it would not be worthwhile to get into a long debate about that at this time.

MR. HEUSS: I would agree, Fred, in terms of the photochemical modeling that you must do to get from the hydrocarbon and NOx emissions to ozone and NO_2, which are the pollutants of concern. The implementation plan run through that is going on now for the models are grossly inadequate and will continue to be for a number of years, I am sure.

DR. STROMBOTNE: I have a comment rather than a question. It is a cautionary note. I heard this morning a couple of speakers refer to the levels of particulates that might be in urban atmospheres in 1985, and I wanted to point out again that the 25 percent penetration of the market figure that we are talking about is 25 percent in the new vehicles. So, with a linear growth curve from zero in 1980 to 25 percent in 1985, you would not see a complete turnover of the fleet until 1995. That is, when the 25 percent figure for the total fleet would apply and the air pollution models should be corrected accordingly. In 1985, with this linear extrapolation or linear growth, I would guess that the average in the fleet would be only six percent.

MR. GROBECKER: Thank you, Dr. Strombotne. Are there any questions which ensue from that? It is a recognition of the fact, that, let us say, only 10 percent of the sales this year are likely to be incrementally new steps. The sales themselves are on the order of only 10 percent of the whole fleet. So, it takes some good long time to get a fleet exchanged.

MR. GIBBONS: Excuse me. I don't want to respond to that. I want to ask another question entirely. Are there responses to Dr. Strombotne's question?

MR. GROBECKER: Will you, please?

MR. GIBBONS: Gibbons of Diesel Auto Association.

I think that we are going to find as intensified laboratory activity occurs that there will be a great number, probably, of compounds that will respond positively on the Ames test. I think that there are serious grounds from the evidence at hand and even some presented today that this is not a meaningful in any real way. In fact, it does not tell us very much. It tells us only that there might be some usefulness in further investigation of certain compounds.

I would like to pose the problem in a different way that perhaps might have larger scale positive advantages. It seems that there is no incidence, and certainly this afternoon we will know much more about the current opinion on this, but it seems that there is no increased incidence of health effects from actual use of diesel equipment of all types, automotive, industrial construction, mining, and so forth, which has occurred over a lengthy period of time, nearly two generations of human beings.

Now, why is this? Why does there not seem to be an increase in, say, carcinogenic activity from this source? What is it about the compounds and what is it about the way in which the human body deals with these compounds so as not to be affected adversely by these compounds? It seems to me that we might find some actual insights, not only into a serious disease, but into the way in which a technology impacts upon human beings. Now, I would suggest that one line of pursuit would be to investigate the -- I am not a biochemist, but it seems to me the term "coplanar" in respect to the way in which the PAH compounds are geometrically structured, biochemical opinion to date seems to indicate that when these, the most biologically active PAH compounds of various types are the coplanar type, that is in which those in which the rings are condensed on one plane, hydrogenation of these compounds distorts the plane from a coplanar form into a number of different geometric shapes which all have reduced biological activity. Perhaps some of the chemists among the panelists could comment on that.

MR. GROBECKER: Do we have a comment on that?

It occurred to me that that is a question, of course, that is also appropriate for this afternoon's session. Do we have any comment on that question from anyone here?

The question as I have it is why haven't we observed in the past years effects on humans of these compounds in diesel engines.

I have an uninformed but intuitive observation that the statistics are just too poor to tell anything at all, whether there have been effects or not. The question is a subject of intensive study, I think at the present time.

Are there any other comments or questions or remarks?

Perhaps I will ask the panel members if they have questions for each other.

MR. STURM: Yes, I would like to ask my colleague down at the far righthand end, I believe Dick Briceland is down there from EPA, if he could give us an update on the status for the 1981 particulate standard for light duty vehicles, both the timetable and what the current EPA thinking is?

MR. BRICELAND: I can probably tell you more about the timetable than I can about the current thinking. Let me review with you what I do know about it. The Congress Clean Air Act Amendments of last fall mandated that the EPA publish particulate standards for diesel vehicles and these were to apply to the model year 1981 vehicles. Now, our current plans are, let me take the autos and the trucks separately, these standards are being developed by the staff at Ann Arbor; and the current plan is that they will come forward on the automobile side with a draft notice of proposed rulemaking packages probably early in June, sometime in the June 1 to probably June 15 time frame, and I just have no idea at this point in time as to how long those will take to go through the regulatory process.

I think we are generally shooting in terms of a January 1979 rulemaking activity on that; but, obviously, there will be a lot of comment on these. We will get them out to the industry and to the interested parties just as soon as we can for input. There has been a lot of discussion about them already, but all I can tell you at this point in time is they are in the final stages of being prepared in draft form. We expect them to come into headquarters probably around June 1, the first two weeks in June sometime.

The truck standard is a little different situation. It is the feeling of the Ann Arbor people that we do not have an adequate transient measurement procedure to do a reasonable job at this time on a model year 1981 particulate standard regulation for emissions from diesel trucks. We do have on the books, already, of course, a smoke regulation or smoke opacities regulation.

We can do something if we have to for the model 1981 truck, but we would feel more comfortable thinking in terms of probably the model year 1983 standard rather than a model year 1981 standard.

So, possibly in the interim period a modification of the smoke standard, if that is judged to be appropriate. Now, this is something that also is being discussed right now, but my understanding of the current status is that we will probably not point toward a model year 1981 truck standard at this time, probably go for something more like a model year 1983.

I cannot give you at this time any indication really of levels of particulate regulations and emission regulations.

MR. TOMBACH: Ivor Tombach of Aerovironment again.

Switching from the modeling role to an experimental role for a second, the General Motors sulfate experiment with its 352 cars, shed a good deal of light under controlled conditions of what was happening in the great sulfate controversy. Then, when followed

Up WITH THE Los Angeles catalyst study, which put it in real urban conditions, has really been rather informative at putting the catalyst sulfate issue into perspective. It seems that it might be appropriate at some time in the future to contemplate a similar type of scenario for the diesel particulate emissions, where one might have some kind of a controlled study away from urban areas and all their complexities to define the short range chemistry aspects of short time and short range chemistry aspects of diesel particulates, sort of extending the dilution tunnel out into the open atmosphere and going another order of magnitude, or two or three, in dilution. Then, at maybe some future time after that, embark into the more complex situation of a real live environment, although I have great trouble fathoming how one is going to sort all the things out in that last experiment.

Anyway, since GM did the great sulfate experiment and since GM seems to be the one in this country that will be introducing at least first the diesel powered cars, I am wondering if a spokesman from GM might want to comment whether they are contemplating such an experiment for diesels?

MR. HEUSS: I already described the CRC project which is aimed at that sort of thing and, most likely, would involve a small number of vehicles in some isolated situation to get a low background. That is our thinking at this point. I think it can be done and will be done.

MR. SPRINGER: I would like to comment on a previous remark, if I could, when you are through with this one, with this topic.

MR. GROBECKER: Proceed.

MR. SPRINGER: I am Karl Springer, Southwest Research Institute. Mr. Briceland mentioned about heavy duty trucks and particulate regulations. I would like to mention that there has been a smoke law in effect on heavy duty trucks built in the United States since 1970, and for the record, to the extent that this full power type smoke law has been reduced over the years and the manufacturers have complied with it, there has been reduction in particulates.

There is, in a general way, a relationship during full power operation of smoke opacity to particulate in the exhaust pipe. So, if anyone thinks that the heavy duty diesel engine has not been controlled to some extent with regard to particulate during these years since 1970, they are mistaken. The point is that this is a relationship that is to some extent valid under full power operation and that is only a portion through an important portion of a vehicle's operation. So, the regulation on particulate from heavy-duty engines has been inherent in the smoke regulations to some extent.

MR. GROBECKER: Thank you, Mr. Springer.
Another question?

MR. HIRSCH: I am Dan Hirsch, NHTSA, and I would like to ask Mr. Briceland a question. You mentioned light duty vehicle particulate standards and standards for the heavy duty trucks. I am concerned about the light duty trucks myself. Will they be treated differently? At present they have different emission standards and different criteria for setting road load horsepower and so on, and we have diesels from at least three manufacturers that I can think of off the top of my head right now, and there will probably be more.

MR. BRICELAND: I will have to find out for you exactly how we are going to handle the light duty trucks, but the light duty trucks will be covered; but I am not sure under which category.

We equally recognize that, not only are there significant fuel-saving advantages there, but there are potentially a lot of light duty trucks, a market potential there. So, yes, the answer is that it will be handled. I don't know which package or which part of which package it will be in.

I have another comment, I think, that I would make about what the gentlemen from the diesel association had asked earlier. Most of the discussion this morning, or a good bit of the discussion this morning, has dealt with the mutagenic type of response to the diesel emissions. There was also some discussion about odor. I would comment that in EPA's looking at the whole diesel question, we make a little bit of distinction between when we say, "health effects" and "environmental effects," and so we are really interested in both. I make that distinction because most of the talk in terms of health effects does talk about mutagenic effects, possible carcinogenic effects, if any; but in the environmental side, we, also, are concerned about the particulate mass question per se, the fact that diesels do have substantially larger emissions than gasoline engines.

I use the number normally 30 to 80. I heard a number, I think, this morning of 15 to 30. Either way, it is a lot. We think that there is the potential that there will be a significant fraction of the current total TSP standards in the vicinity of roadsides that could be attributable to the diesel emissions, if we get into the 25, 35 percent sales category in the 1985 time frame.

So, in addition to the mutagenic type of health characteristics or health issues, we are also very interested in being careful about what is the effect of the mass particulates per se.

I, also, have the feeling that odor may be a real sleeper here for us; and, as far as the Environmental Protection Agency is concerned, it may be something that we will want to be paying a lot more attention to than we have in the past.

I don't think we quite know how to deal with this yet, but I think it is something we will have to look at much more carefully than we have.

MR. LEVINS: If I might, I would like to share another bit of information we have on that issue. Most of the discussion around particulates and PNA are essentially related to long term chronic effects, chronic health effects; certainly significant, but different than just the sort of thing you are talking about now, which I might choose to describe as acute effects, the immediately observed effects, whether it be particulate, increased particulate load in terms of welfare effects like soiling or simply impact on the non-participating community, people who are not driving the cars.

We did a very interesting experiment for a manufacturer, an engine manufacturer, a short while ago that pointed this out very dramatically. It introduces a second term, which we don't really need in the diesel problem area right now but, nevertheless, is there and is going to gain increasing recognition whether we want it to or not, as we start to dieselize.

We have talked about odor as a nuisance issue for some time now, and there have been a lot of studies done on that. Associated with the chemistry of the odor and as a separately perceived physiological effect is the irritation associated with diesel exhaust. Anybody who has been holed up with diesel exhaust for any period of time knows that it gets to the eyes and nose and is pretty dramatic. Where that is in terms of the species relative to your comments, Dick, about the truck in the bay area sort of thing, is important to understand.

We did some experiments where the diesel engine itself was being used to transport the vehicle through the production line, and there was about a two-hour duty cycle where employees were being exposed. Employees were complaining, and there were threats of shutting down the operations. So they needed to do something. We investigated for short term application, the use of a charcoal cannister to remove the odors and irritants in that environment. The experiments were very successful, not practical for solving the road problem, but very successful and practical for that particular application.

In essence, the two controlled experiments that we carried out went something like this. It was a small area about half the size of this room in which two large diesel engines were running. We had a group of about one dozen people, both assemblers on the line, those of us who get paid for that kind of torture, and some supervisory personnel as well. Without the cannister on the engine and the engines running with ventilation in the room set to control carbon monoxide at 50 ppm. So, we had some other criteria to work with. Everyone voluntarily left the room within about a five-minute period. It simply became intolerable even for those of us who were paid to make the observation. The eyes were streaming, the nose was irritated; it was pretty nasty.

With the charcoal cannister on the systems, we were able to make our observations and record our data for an hour period; and the cannister, in fact, is effective for about two hours. It simply points out that there are irritation effects that are going to be very significant as the percent population of diesel picks up and it starts to accumulate on the sidewalks; and that in these experiments anyway, there is a fair bit of evidence that says that those sort of factors are certainly associated with things in the gas phase at the exhaust level, the kind of things that can be removed by charcoal filtration.

These devices had virtually no effect on the particulate emission levels, a very small percent reduction in particulates out of these cannisters.

So, intterms of separating the two effects, those were pretty dramatic experiments for us.

MR. GROBECKER: I think, since it is now 12:15, we will conclude this session. Let me, in behalf of all, thank the speakers and the panel members.

DR. MILBY: Let us come to order. My name is Tom Milby. I am chairing this session on health effects. minor Dr. Herman Kraybill, who is back a couple of rows here, has kindly agreed to chair the panel discussion. I will introduce him a little later as we go.

Our first speaker of the afternoon is Dr. Mario Battigelli. Dr. Battigelli is Professor of medicine from the University of North Carolina at Chapel Hill. Some years ago, Dr. Battigelli did a great deal of work on the effects of diesel exhaust emissions not only on experimental animals, but also on humans. He kindly consented to come and speak to us this afternoon on that subject.

(Written paper follows.)

Physiological and Pathological Aspects of Dust Inhalation

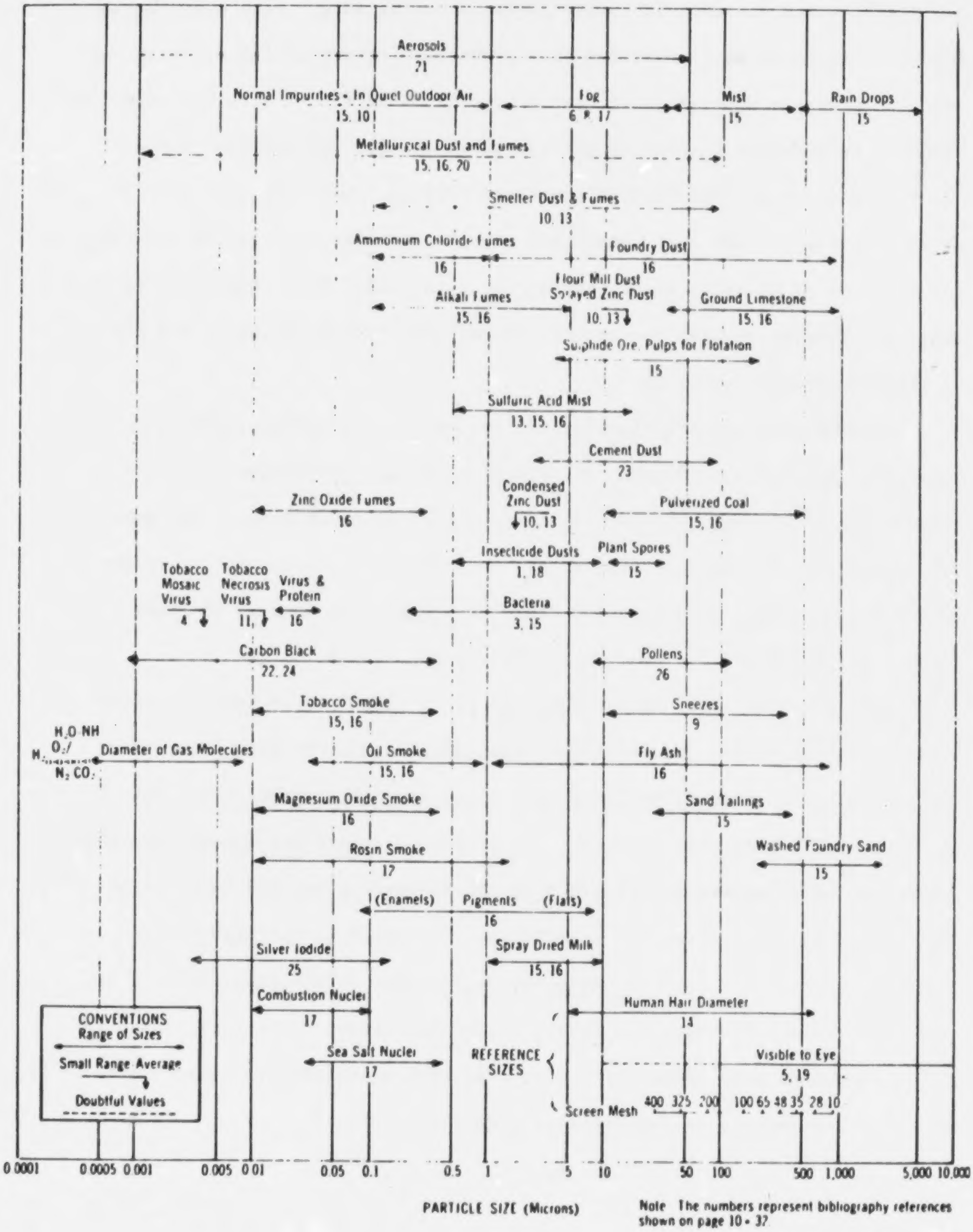
M. C. Battigelli, M.D., M.P.H.
Professor of Medicine
UNC, School of Medicine
Chapel Hill, NC

Two points must be stressed in discussing the physiology of dust inhalation. The first states that the respiratory apparatus of the air ventilating animal is a very efficient scrubber. As John Tyndall demonstrated very well over a century ago, the expired air contains very few light scattering particles, as the Tyndall phenomenon can persuasively demonstrate. Indeed, a large majority of the particles we breathe are retained, for some time at least, on the surfaces of the respiratory system. Fig. 1 reports the size of common airborne dust.

The second point of equal importance, is that this phenomenon, the deposition and clearance of dust in the lung, as many other fundamental aspects of biology and medical biology in particular, may appear to be deceptively simple. Indeed, it is terribly complicated.

The respiratory function consists essentially of two phenomena. Through circulation we pump blood over a large surface, the pulmonary capillary network of the alveolar tissue in order to have the blood properly oxygenated, and at the same time discharge the waste product of tissue metabolism, namely carbon dioxide. In the opposite side of the alveolar membrane, a proper amount of air has to be ventilated over this large surface. The estimated surface of the gas exchanging portion of the lung has the rough size of a small tennis court, about 50 m^2.

the sizes of air-borne contaminants



Note The numbers represent bibliography references shown on page 10 - 37

FIGURE 1

The ventilatory function is what carries dust as well as other extraneous materials, which are ubiquitously present, into the lung. With every breath some dust is inexorably deposited within the respiratory surfaces. Figure 2 emphasizes that a population of dust particles is in fact a very heterogeneous cluster, requiring a complexity of indicators for its definition. Any dust cloud is made up of individual elements of varying dimensions, not only in terms of diameter, the most common and perhaps the most informative parameter, but in terms of density, shape, surface area as well. This complexity is an important element we need to consider in defining dust behavior in the context of the respiratory apparatus.

The mean size and its distribution parameter, the delta or standard deviation, are the most common and most popular characteristics of a dust cloud. One of the most popular statistical indicators is that of the mass mean diameter, because it satisfies the toxicologist's desire to use weight in discussing dose. The mass mean diameter defines the size of the dust cloud, which divides the dust mass in two equal halves.

There are four major events that one has to identify to understand the kinetics, the dynamics of dust inhalation, dust deposition and dust effect. One is the penetration of the dust into these crooked, narrow, long, wet passages that we call the airways. The second considers the deposition, that phenomenon which remove a particle from the airborne phase and lands it on the surface of the respiratory structures. The third is the clearance phenomenon, which competes in establishing the dose at the critical site of dust deposition. Finally, the fourth is the biological reactivity, which in itself compounds many elementary functions, such as solubility, tissue reactivity and the other factors of toxicological importance.

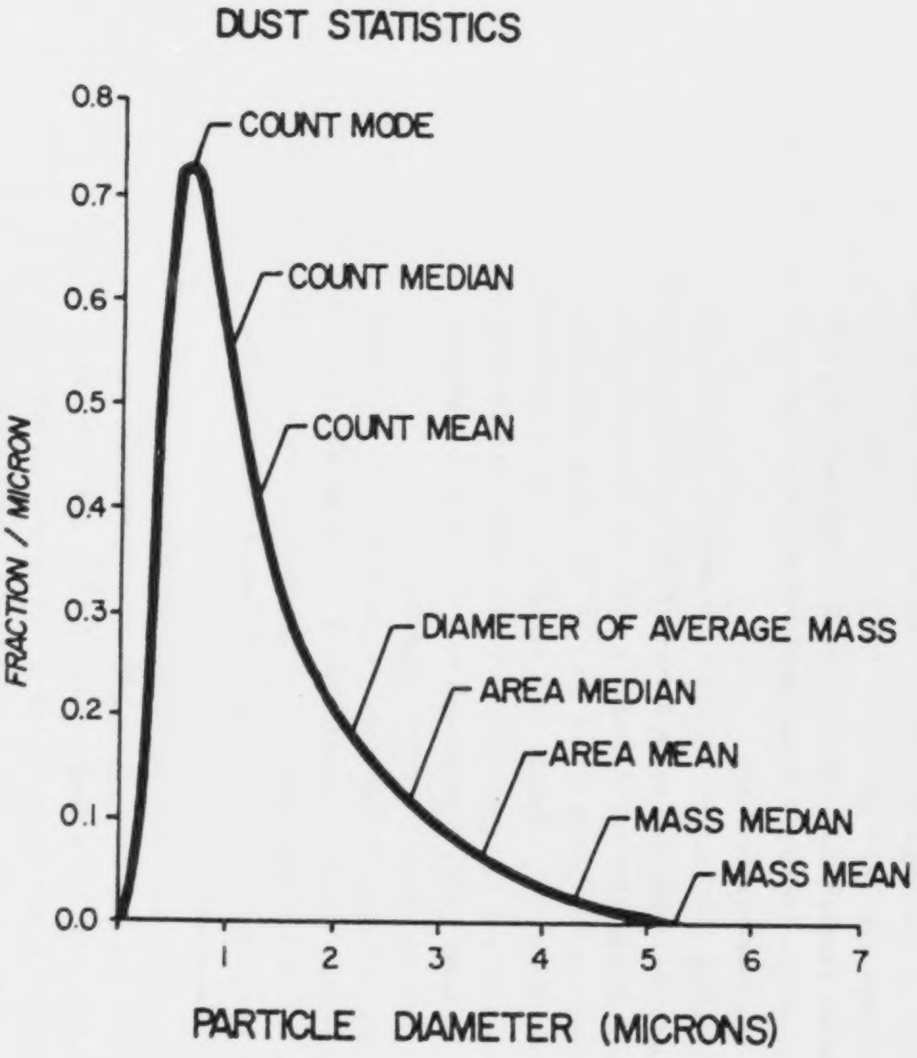


FIGURE 2: Statistical Parameters of Dust Clouds

Fig. 3 described the penetration of a particle in function of its size. The immediate information that one can derive from this is that particles above 10 microns in diameter have very little chance to penetrate deep into the respiratory apparatus. They are trapped on the very upper portion of the respiratory tract. This diagram describes, schematically and oversimplifying, the complex nature of the phenomenon, what is our understanding of the airways penetration of an idealized dust cloud. The righthand side of the diagram describes the upper portion of the airways. The lefthand of this bimodal distribution reflects the lowermost portion, that situated beyond the bronchial tree, involving the non-ciliated aspects of the respiratory tract.

In following our list of important parameters, we must not omit the fact that breathing has a direct relevance on the eventual establishment of the dose. The deeper portion of the respiratory apparatus when the subject breathes through the mouth, bypassing the upper portion of the airways, will receive a greater quantitative load than it may be experienced when the dusty air is ventilated via the nose. Fig. 4 indicates some of the most important aerodynamic factors controlling dust penetration.

The term aerodynamic diameter, as you recognize, is a sort of elaboration and indirect description of the physical aspect of the dust cloud, which incorporate density and shape characteristics of the dust, offering a more relevant and descriptive value in relation to deposition.

A nice way to find out the validity of what is discussed here is to analyze a dusty lung, a lung of an individual who has been exposed to dust for a long period of time, and then, by careful particle analysis, establish if our theory and our prediction in regard to the relationship between particle size and deposition, were indeed correct. This has been done

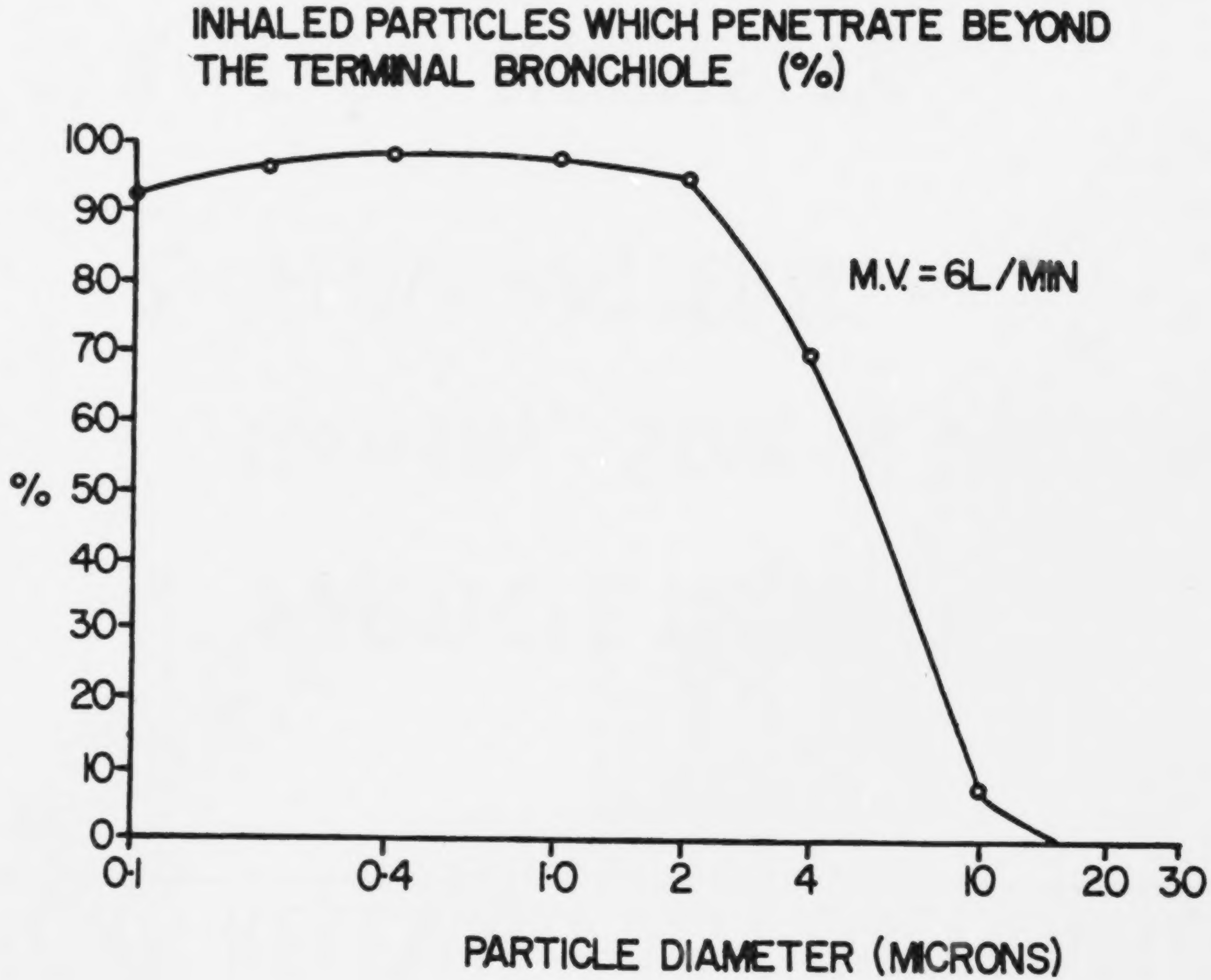


FIGURE 3: Size vs. Deep Penetration of Dust in Lung

FIGURE 4

FACTORS RELEVANT TO PENETRATION

1. PARTICLE INERTIA
   (Density, Size, & Velocity)
2. FLOW PATTERN
3. FLOW INTENSITY

repeatedly through careful and extenuating studies, involving electromicroscopy readout and utilizing lungs of individual casualties or deaths , from the dusty trades, such as coal miners, foundry workers, and other dusty tradesmen of one variety or another. There are several excellent studies in the world literature. (*) (**).

Figure 5 has been extracted from these studies, and it portrays frequency matched against the dust diameter. You will see that the respiratory apparatus has a selective sample size characteristic, (the different graphs reflect different densities or different chemical composition of the dust. The x's and the open points reflect coal dust. The triangle reflects cilica dust exposure). You can immediately derive that probably 99 percent of the dust retrieved from human lung has a particle size which is less than eight or nine microns. Indeed, we find here a great deal of verification of the theoretical predictions on dust penetration and deposition in terms of diameter. Particles larger than ten microns are almost irrelevant in terms of respiratory penetration and, therefore, toxicity. They will either have great difficulty in penetrating or, if they do penetrate, their numbers will remain inconspicuous.

Attention should be directed here to the entirely different behavior displayed by long particles, such as fibers, which indeed seem to violate this principle, which therefore applies only to non-fibrous airborne dust only.

The mechanism whereby a dust particle ceases to be airborne has been identified into one or more of four distinct processes (Figure 6). Contact is operating whenever a particle is too close to the wall and is impinging or impacting on the surfaces. Gravity, which is probably the most important factor, settles out dust quite effectively. This is important for any dust cloud, in the respiratory airways as well, but one must realize that it applies

(*) Casarett L. J. "The vital sacs: alveolar clearance mechanisms in inhalation toxicology", in Essays in Toxicology, W. J. Hayes Jr editor, vol 3, Ac. Press. 1972 pp 2-36

(**) NAT. RES. COUNCIL "AIRBORNE PARTICLES", N.A.S. Washington DC 1977

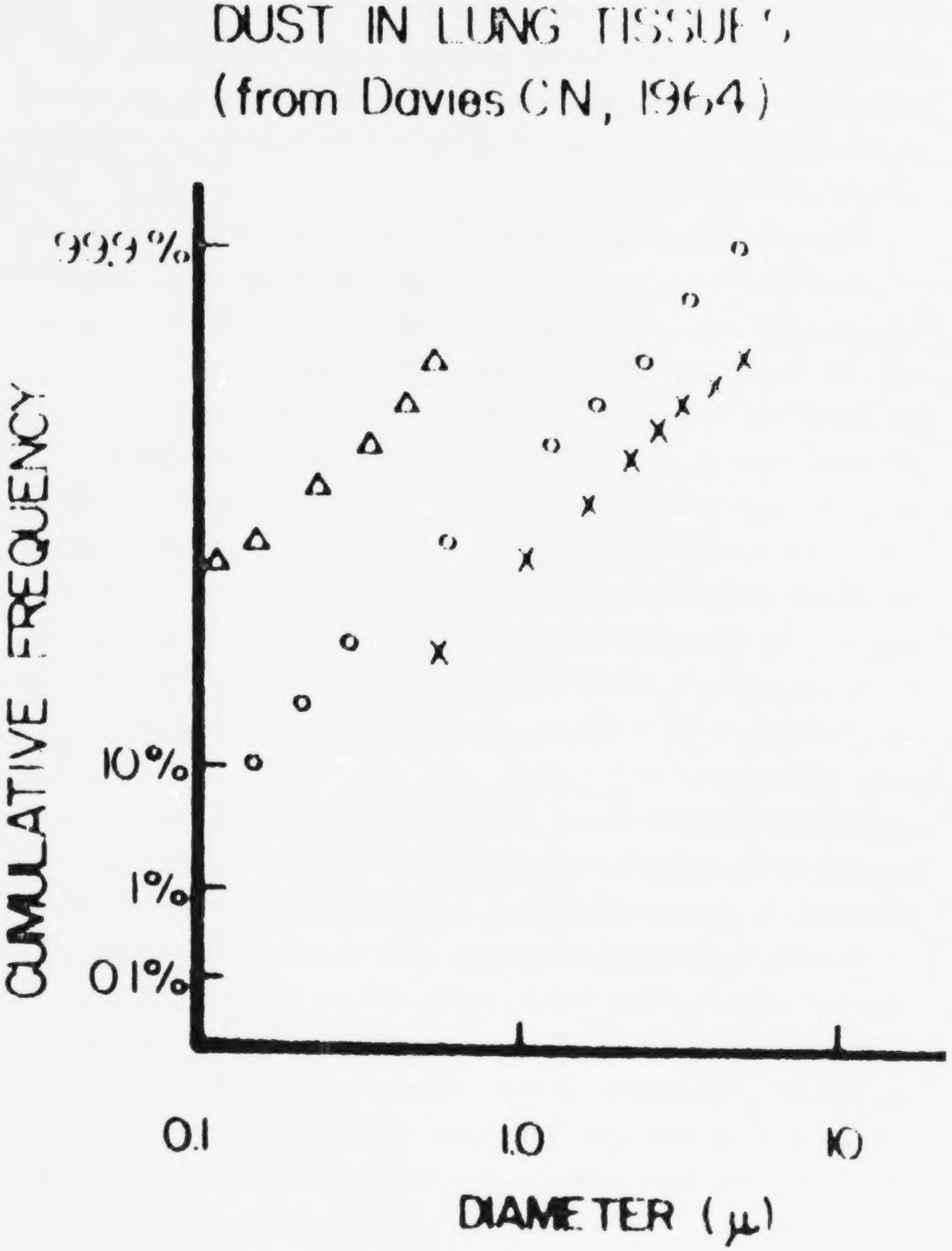


FIGURE 5: Dust Recovered from Human Lung

FIGURE 6

MECHANISM OF DEPOSITION

CONTACT

GRAVITY

MOMENTUM

BROWNIAN AGITATION

to dust particles of a specific size and density. Very small particles are not affected much by this. The third is the momentum. The dust particle does not make the bend of the airways and it impacts on the facing surface. Finally, and also most important, for the deepest penetration and deepest deposition in the respiratory apparatus, is difussion or Brownian phenomenon, affecting very small. dust. This continuous agitation of dust may cause its contact and deposition on nearly surfaces.

The overall dose is determined by penetration and deposition and by the opposite processes tending to clear the deposited dust from the airways. Clearance happens according to different modalities, of which three are indicated in Figure 7. These are namely solubility, whereby the dust particle dissolves and disappears from the respiratory apparatus, the ciliary escalator, which is the cleansing mechanism, the backbone of the defense mechanism of the airways, and the parenchymal penetration. Phagocytosis, blood and lymphatic drainage et cetera, also converge in removing the dust from the surface aspects of the airways.

There are important distortion factors in dust deposition which need to be taken into consideration (See Fig. 8). Observing the anatomical pathways followed by a dust particle, just entering through the nose and going deep into the respiratory cavities, one realizes these pathways are very tortuous, narrow, and rather effective in trapping large dust matter. The bone projections, in the nose cavities, are wrapped up by soft spongy tissue, narrowing the opening of the cavity to the size of a slot about one millimeter in diameter in some places. The anterior portion of the nasal cavity is the section which might rightly be called the garbage dumping ground of our respiratory system, where most of the particles, particularly the larger ones, tend to land. Nose blowing is an effective means to document this function.

DOSE

PENETRATION

DEPOSITION

CLEARANCE
- SOLUBILITY
- ESCALATOR
- PARENCHYMAL PENETRATION

FIGURE 7: Factors of Dust-Dose

FIGURE 8: Distortion Factors with Dust Inhalation

"DISTORTION" FACTOR

1. AGGREGATION
2. CONDENSATION
3. ELECTRICAL CHARGE
4. THERMAL EFFECT

If an individual is exposed to a properly tagged cloud of dust, it can readily be demonstrated that the tip of the nose is where most of the activity will be initially located (See Figure 9).

Figure 10, in a slightly different perspective, is a summary of what we have been discussing. The larger particles above ten microns impinge on the very upper portion of the respiratory tract, in the nasal cavity or the very upper portion of the airways. The middle ground, namely the tracheobronchial tree, is where the particles between ten and somewhat less than one micron are trapped following sedimentation settling forces. Finally, the smaller particles have a bimodal distribution, favoring their deposition at the very deep ortion of the lung.

The cleansing mechanism is operated also by cough, which is one of the most formidable defenses of the airways, and by ciliary clearance, which is the result of the activity of these appendix-like structures which line the airways, continuously beating in an organized fashion, sweeping fluids and whatever these fluids carry on toward the larynx, to be in turn swallowed.

The ciliary structure, however, ceases to be present at a level just below the peripheral canalicular structures of the bronchial tree, the terminal bronchioles. Beyond that area, there are no cilia. Therefore the escalator is not available on that section. The process of moving dust from the deeper portions, such as the alveoli, up to the escalator, the very treadmill which will eventually provide the ultimate clearance, is a matter of some uncertainty. Many hypotheses have been proposed, few facts have been unequivocally demonstrated.

Figure 11 demonstrates that a diesel particle can indeed reach the deeper portion of the respiratory apparatus. This illustration comes from an experimental preparation , using rats exposed to undiluted diesel exhaust.

FIGURE 9: Dust Deposition

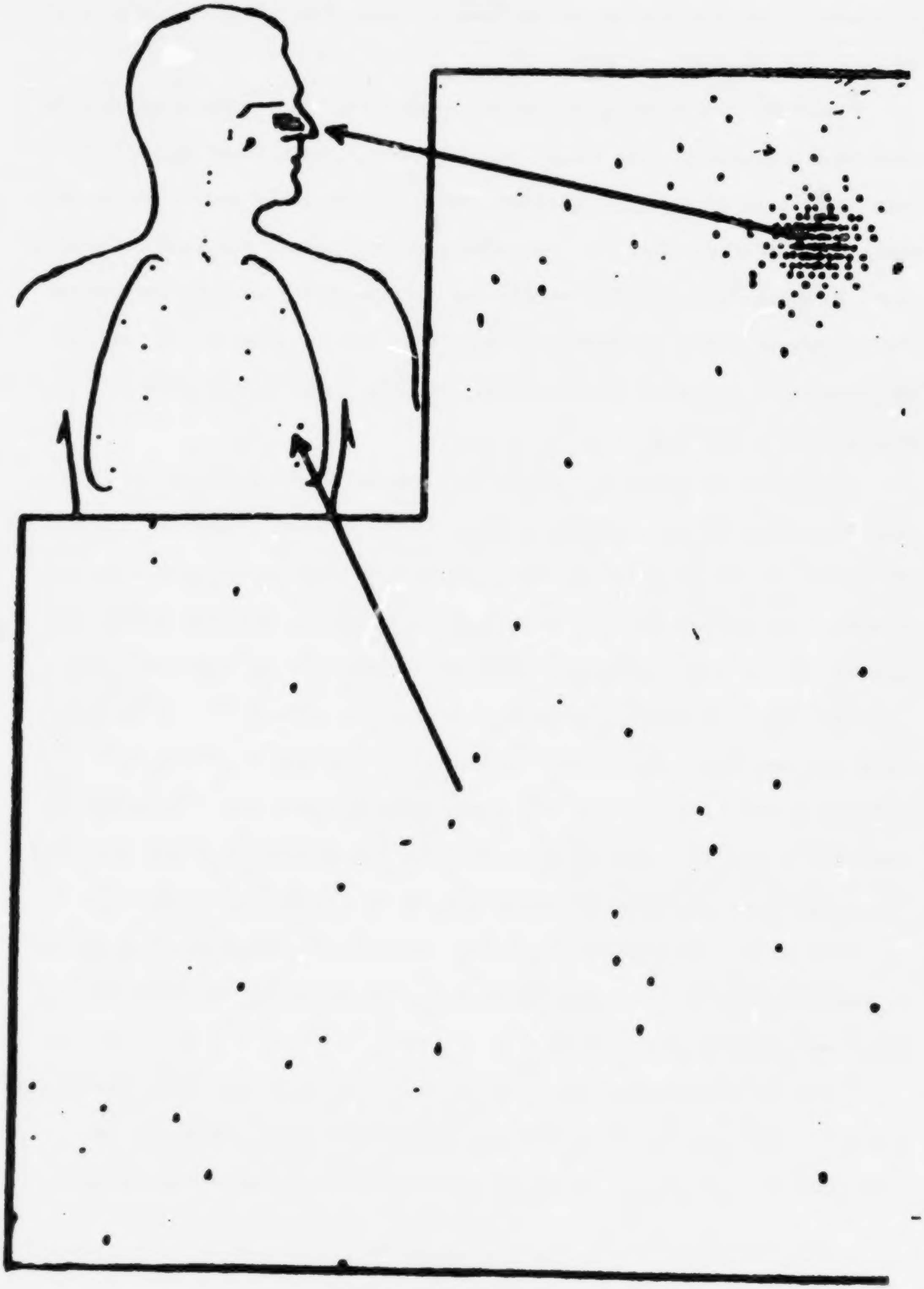
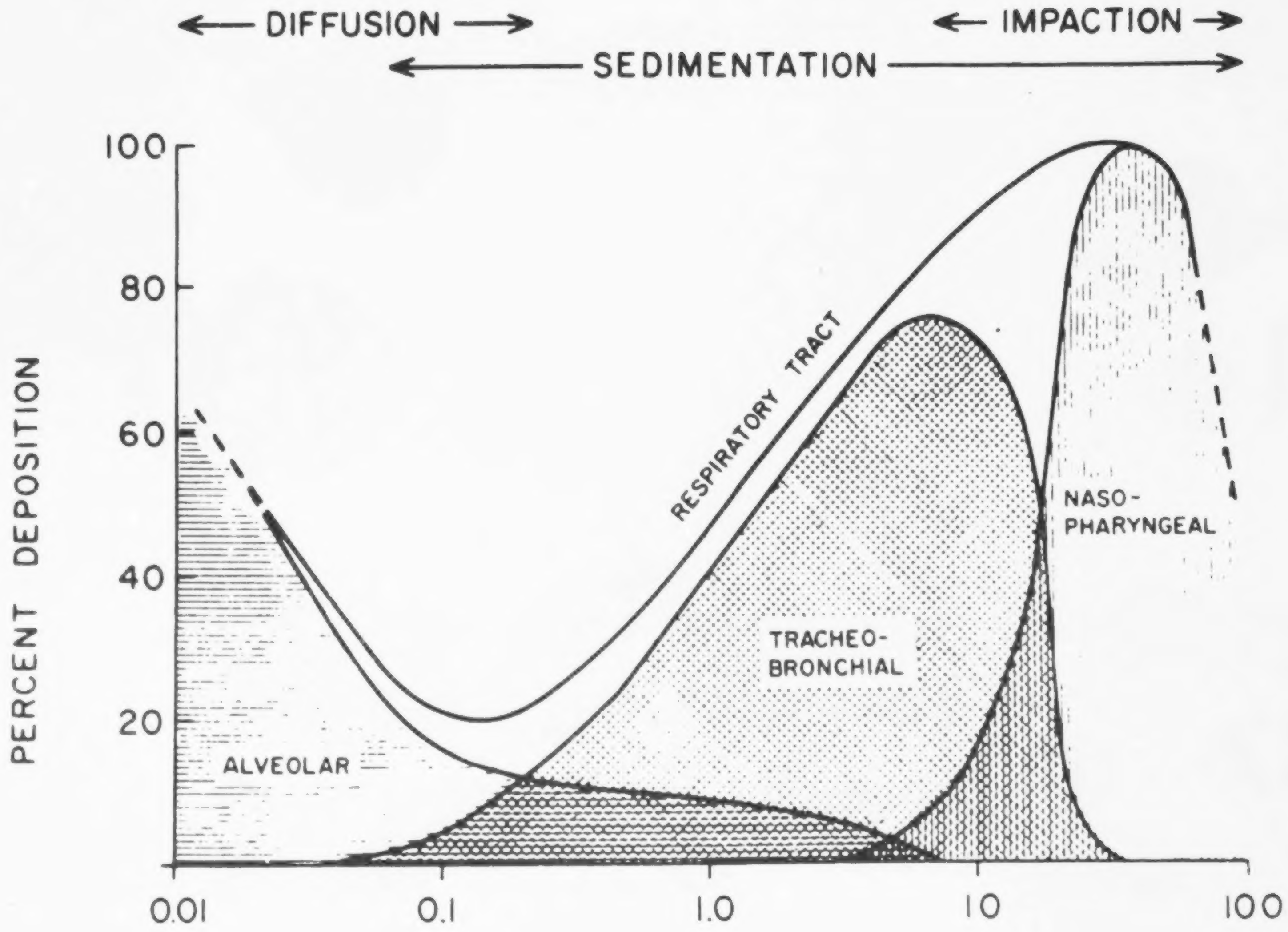


FIGURE 10: Size Factors with Deposition



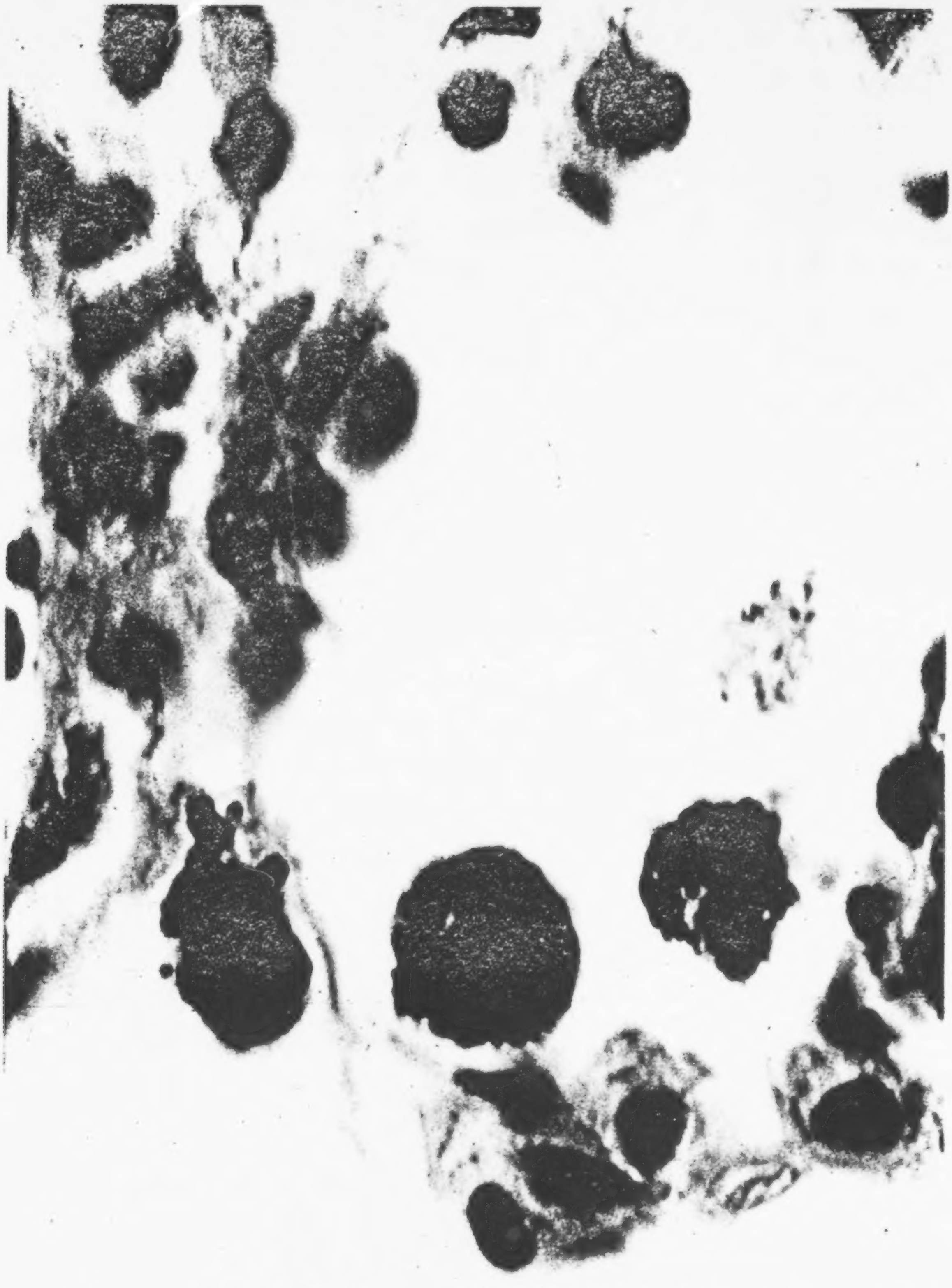


FIGURE 11: Dust-laden Cell with Alveolar Spaces

The scavanging cells, which are not always evident, but are present in the most peripheral portions of the lungs, on arrival of the dust, provide a very effective although not totally adequate mechanism of clearing up and collecting the dust by methodical ingestion, eventually being swept up toward the escalator by whatever mechanism is at play, or may persist in the alveolar area, or alternatively, may be absorbed within the thickness of the structure of the alveolar tissues. This phenomenon of clearance has been studied most intensely under the interest dictated by radioactive aerosols. In this connection, a variety of models has been proposed, none of them being entirely satisfactory.

One of the better known, which has the merit of great simplicity and a convenient terminology is indicated in Figure 12. Three areas are recognized. The upper portion of the airways is called NP for nasopharyngeal, a middle portion, TB for tracheobronchial, and the peripherial portion where the gas exchange phenomena take place. All three may eventually feed to the drainage by the blood or by the lymph, as indicated in the left hand side of the diagram, or, more commonly, they may feed into the escalator, using the GI tract as the eventual disposal port.

Figure 13 illustrates the ciliated epithelium. The cilia beats at a frequency of around 1,000 beats per minute. They propel the fluids in which they are immersed at a variable speed, which has been gauged by a variety of observers to range in humans at the level of the trachea, between ten and 20 millimeters per minute, following a lower speed in the more peripheral portions of the lungs, reaching a fraction of one millimeter in the very peripheral area where cilia are still present.

FIGURE 12: Model of Dust Deposition and Clearance

DEPOSITION AND CLEARANCE OF DUST IRCP SCHEME, 1965 (modified)

DOSE EXPIRED = E
DOSE INSPIRED = I

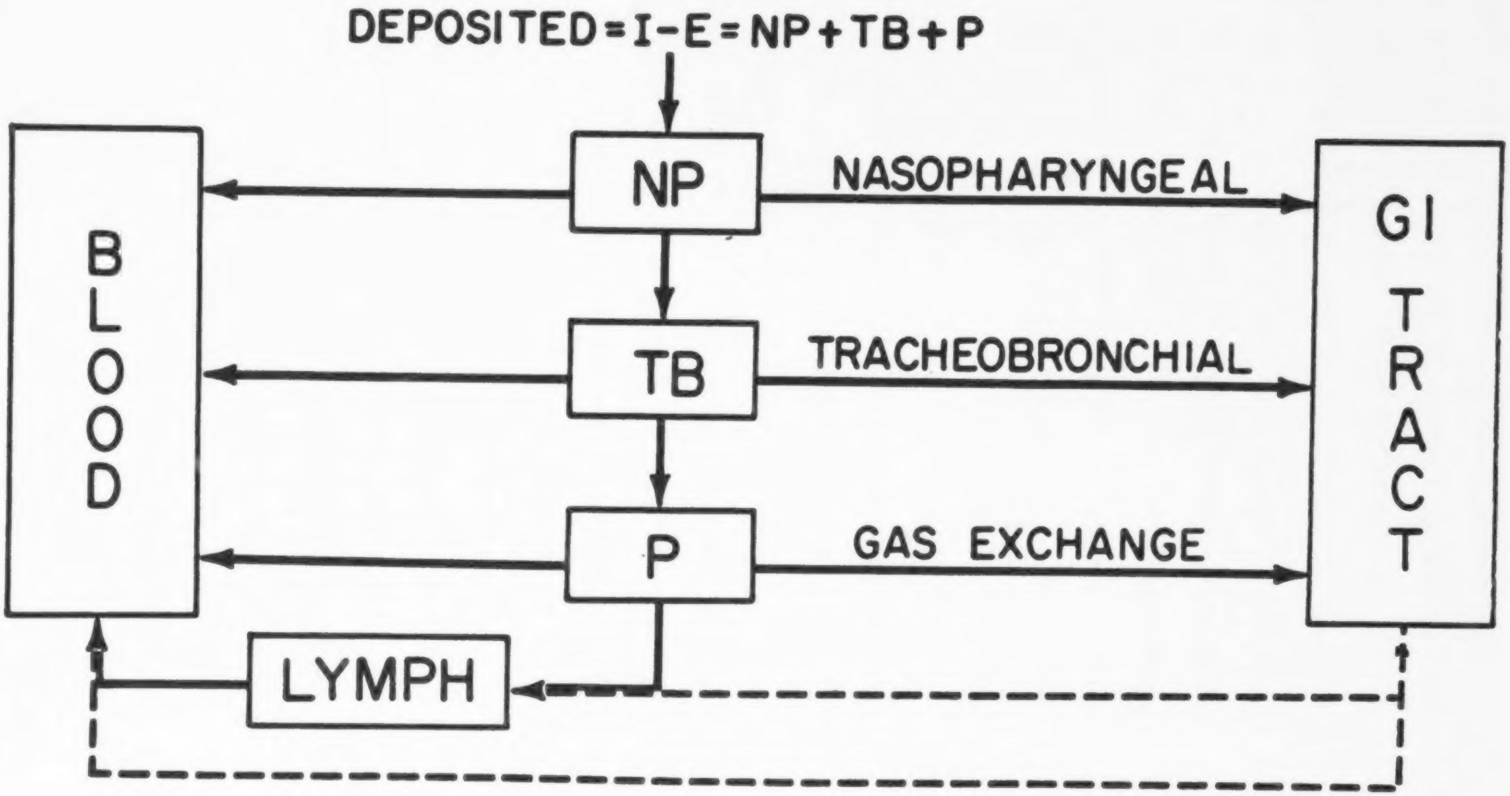
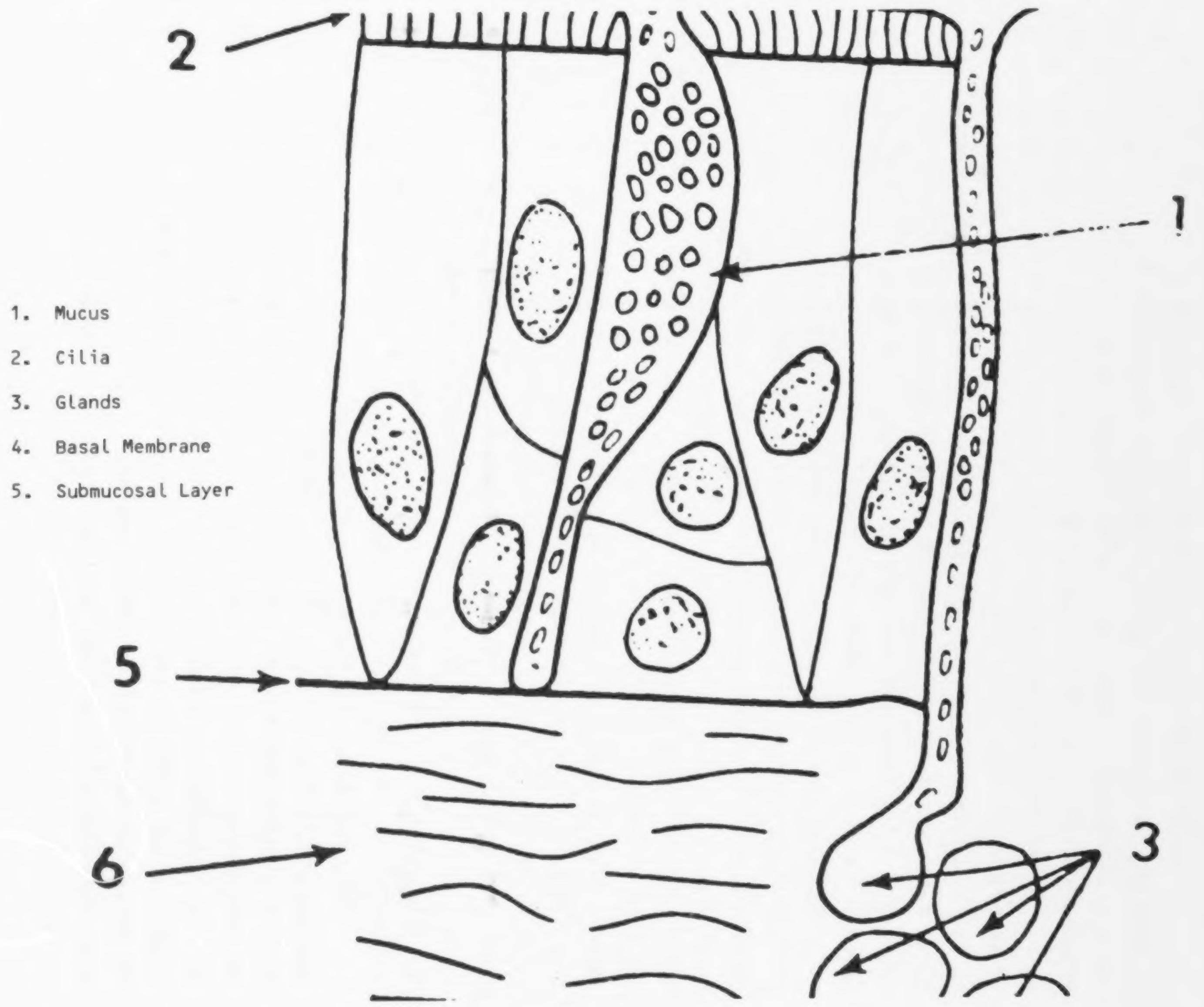


FIGURE 13: Schematic of Ciliated Epithelium



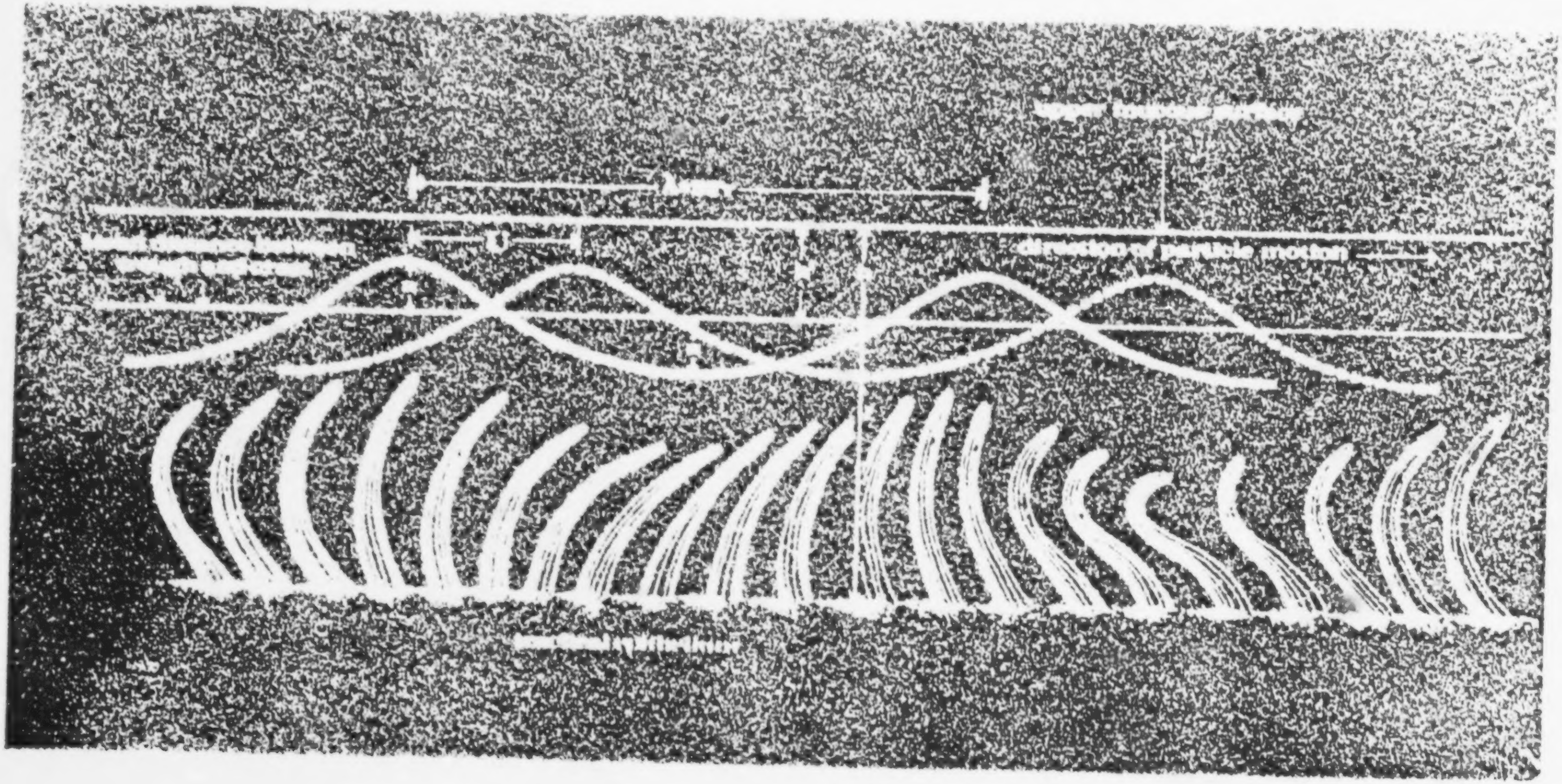
1. Mucus
2. Cilia
3. Glands
4. Basal Membrane
5. Submucosal Layer

The mechanism of ciliary beat follows a very organized pattern of motion (Fig. 14), which is not exactly synchronous, but is a metachronic motion with a slow backward sweep and a fast forward push which provides a very effective advancement of the mucous layer. The structure of the cilia, enormously magnified, is quite complex (Fig. 15). The real motor, the centriole, is in the thickness of the cell. This structure is amazingly reproduced throughout a wide variety of phylogenetic species and, in fact, within the mammalian body in different unrelated organs, whenever these cells have cilia processes.

The cleansing processes, as I mentioned, are essentially identifiable in the ciliary sweep, in the tidal excursions, a mechanism which is not as yet well identified, and finally, in cough (Fig. 16). Fig. 17 indicates a rather dramatic representation, the cleansing effectiveness of cough. This is the experience of human subjects who, having inhaled a cloud of radiotagged, dust, are followed through external counters in terms of their expectoration effectiveness. The top portion of Figure 17 reflects the performance of a normal healthy individual, and the lower portion a bronchitic individual. You see that in both these instances, the cough has a very dramatic effect in reducing the radioactivity and, therefore, reducing the amount of dust present at the site probed by the collimated probes.

The reaction of the respiratory tissue, for simplicity, has been grouped in Figs. 18, 19, into two distinct portions. Fig. 18 reports the processes commonly involved in the airway reaction. Immediately, one recognizes the muscular contractions as one of the most ubiquitous reaction of the particle inhalation. It depends on the nature of the particle, the intensity of the dust, the particular status of the airways exposed. Cough is often associated with muscle activation. The result is a change in the bronchial patency, with modification of the

FIGURE 14: Ciliary Motion: A Schematic



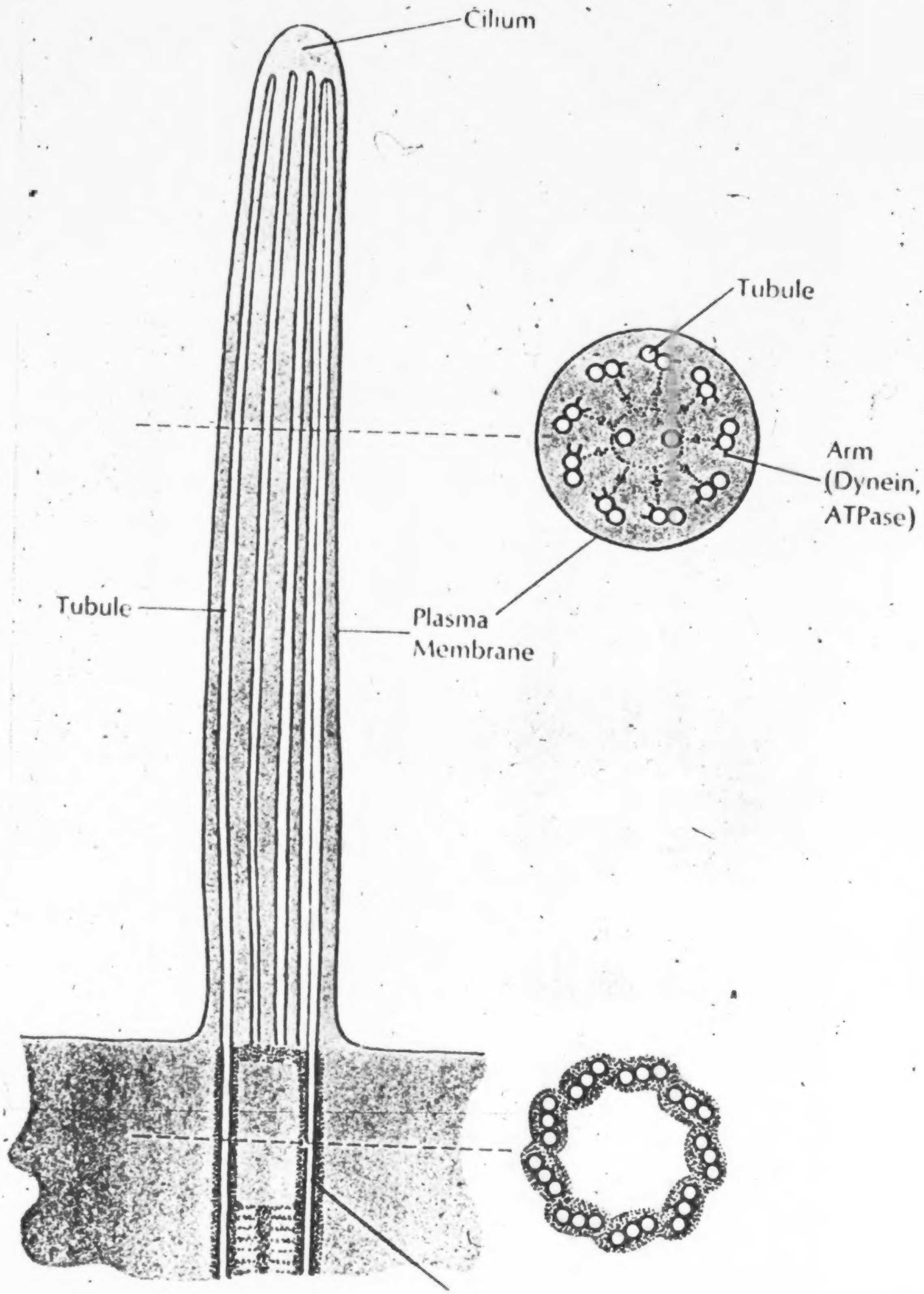


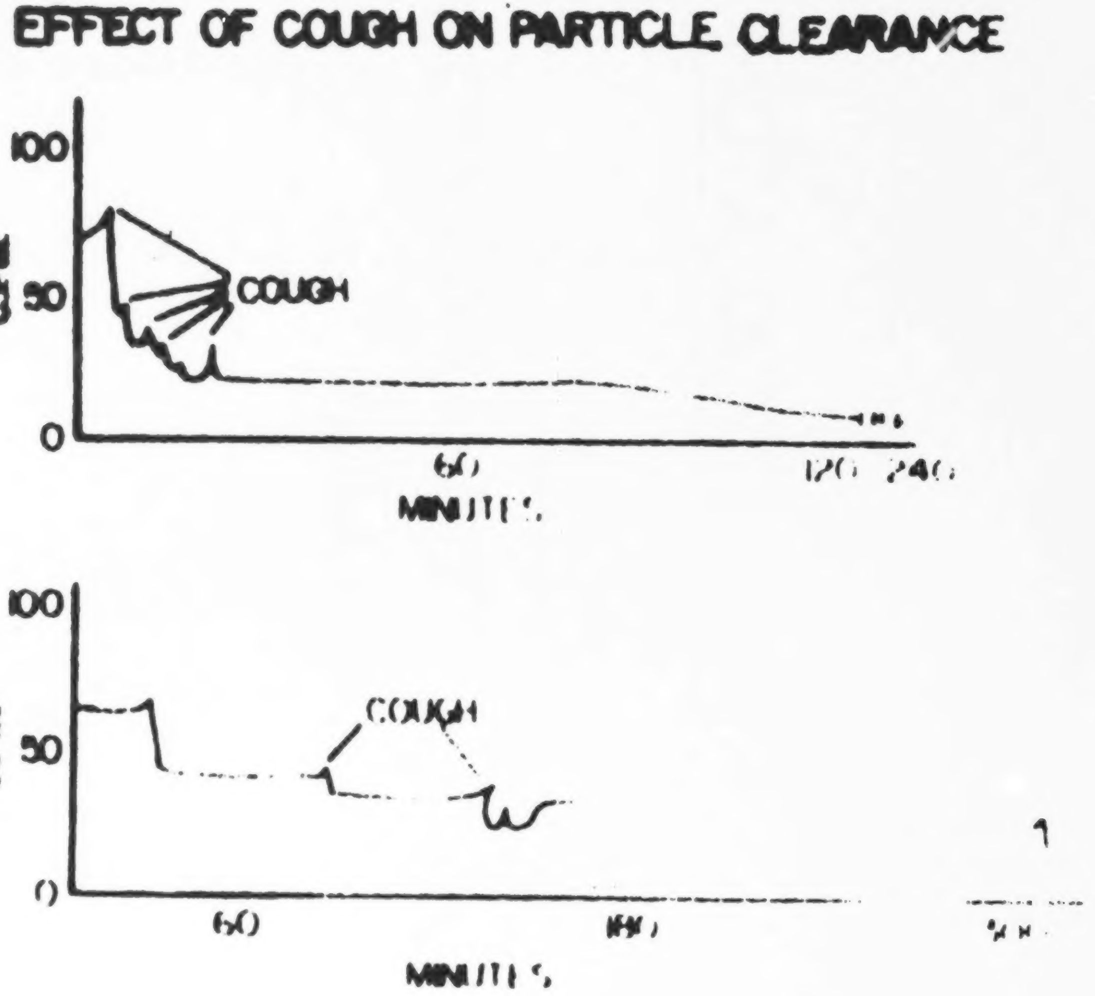
FIGURE 15: The Schematic of a Cilium

FIGURE 16: Dust Escalator

ESCALATOR

CILIARY
TIDAL EXCURSIONS
COUGH

FIGURE 17: Effect of Cough on Dust Clearance (from Toigo et al, ARRD, 87: 487, 1963



BRONCHIAL WALL REACTION

Muscle Contraction

Vasodilatation

Mucosal Edema

Mucosal Gland Secretion

FIGURE 18

FIGURE 19

ALVEOLAR REACTIONS TO DEPOSITED PARTICLES

EDEMA (experimental)

PHAGOCYTOSIS

PROLIFERATION

FIBROGENESIS

diameter and the geometry of the airways. There are perhaps vascular phenomena which subtent the muscle activation. There may be mucosal edema if the exposure is intense and sustained. Finally, increase secretions may be the common result of irritation.

Again, I would like to stress that these are very schematic and very general modes of response and their relevance to a particular dust cloud may be quite variable.

The deeper portion of the respiratory tissues may respond in a variety of manner, including fluid exudation or edema, a phenomenon which requires a very intense exposure, phagocytosis, and cellular proliferation if the dust dosage and dust characteristics are adequate, and, finally, by the ultimate result of cellular activation, namely fibrogenesis.

A commom result of breathing dusty air is soot accumulation in the human tissue, a common result of this is among others, long standing cigarette smoking. Dust often tends to accumulate surrounding the space of disrupted architecture. We recognize emphysema as one of the possible reactions of dust exposure and dust deposition particularly in connection with discretecoal dust deposition.

Where dust is accumulated in substantial amounts a variety of reactions may follow, including proliferation of cells. In this fashion a significant scar may be formed.

The functional mechanism of injury, in general, can be classified in terms of physio-chemical effect, of which the foreign body reaction is a variety, in terms of toxic, where something more than the foreign body reaction is present, in terms of immunological reactions, where other processes may be involved, and, finally, the neoplastic and/or oncogenic effects which have been widely discussed elsewhere. (Fig. 20).

MECHANISM OF INJURY

PHYSICO-CHEMICAL (Foreign Body)

TOXIC

IMMUNOLOGICAL
- Allergen-Reagin (Asthma)
- Antigen-Antibody (Farmer's Lung
- Delayed Hypensensitivity

ONCOGENIC (Hydrocarbons, Cr, Asbestos, Isotopes, etc.)

OTHER (?)

FIGURE 20

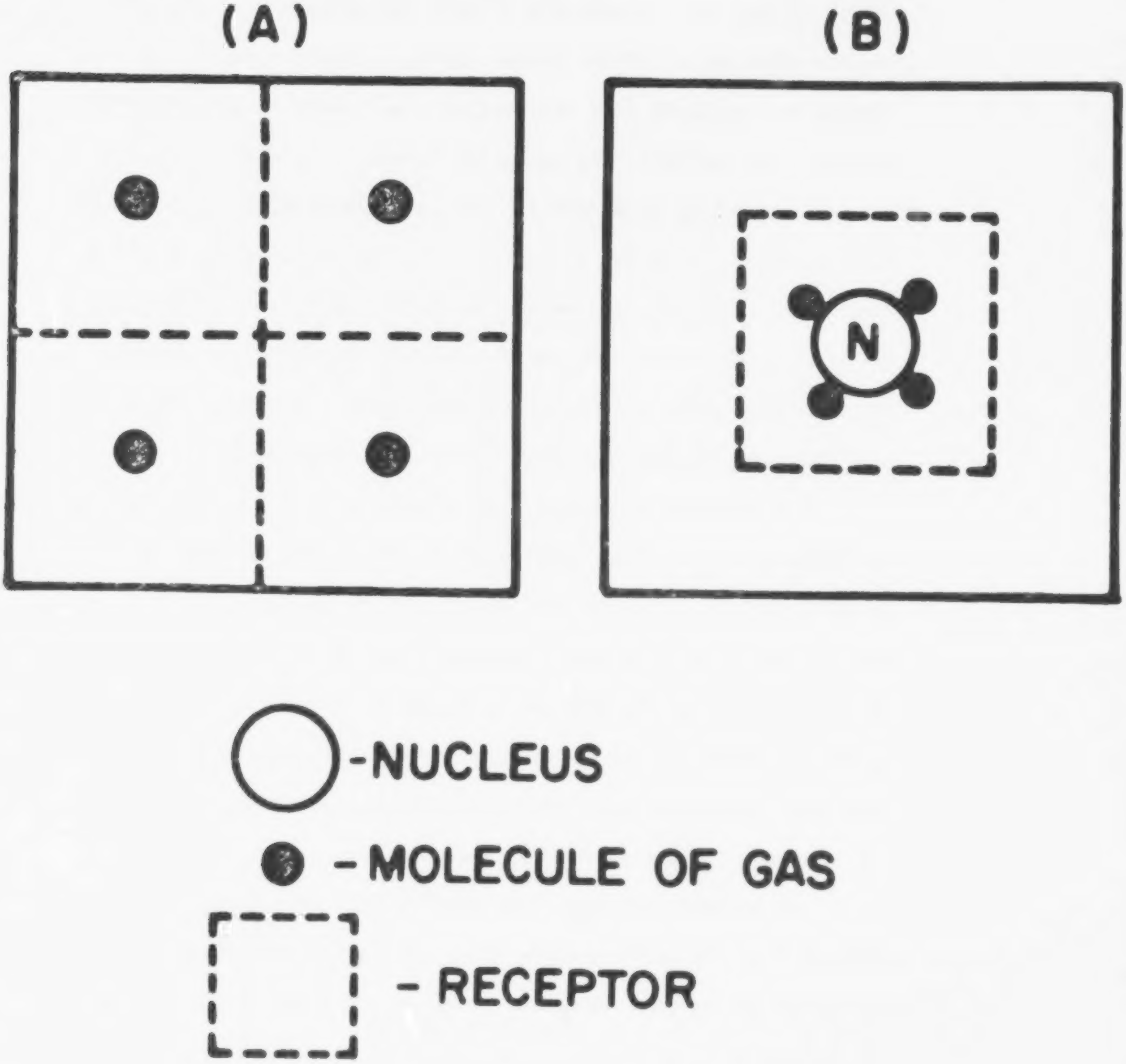
Last, and perhaps not least, is a very special responsibility which has been attributed to dust, in terms of the gas absorptive characteristic of dust, which is grossly indicated in the simplified sketch of Fig. 21. A particle of dust may operate in a synergistic fashion with gas by either concentrating a chemical which can be carried or localized at a critical site and reach an effective dose through this concentrating mechanism exercised by dust. The dust may work as a piggyback carrying the gas molecules to a deeper site of deposition, which the gas by itself without the presence of the dust could not reach otherwise. As you all know, this mechanism has been widely discussed, particularly in attempting to explain, for instance, effects from air pollution when gaseous contaminants were detected in less than "effective concentration."

As a conclusive comment, let us open a dictionary and look at the meaning of the term "inspiration." The first explanatory comments state that "inspiration" is the act which moves the intellect and the emotions. The second meaning that any elementary dictionary will offer is that inspiration is an act of drawing air into one's lungs. A third,meaning may be added, realizing that inspiration is also the phenomenon which brings gaseous contaminants and dust into the context of our respiratory tissue.

Let us hope that the first meaning will move enough wisdom and care so that the third meaning will receive all the appropriate attention and prudent discussion that its complexity well deserves.

FIGURE 21

CONDENSING EFFECT OF PARTICULATES



(A) - NO EFFECT

(B) - EFFECT

DR. MILBY: Thank you, very much, Mario, for setting the background for us.

Our second speaker is Dr. Vostal from General Motors, who will discuss with us the health effects of diesel exhaust particulates.

DR. VOSTAL: I have just tried to explain to Dr. Milby that according to the modified program, which has been distributed to all participants at the time when they registered, the second presentation should have been done by the representative of the EPA to talk about their plans and existing activities in the field of the health effects of diesel exhaust. But, I am perfectly willing to take over and to explain in a very brief presentation what the activities are in the laboratory with which I have been affiliated for the last four years.

My background is in medicine and in occupational and environmental toxicology. About four years ago, I joined General Motors Research Laboratories and I have been given the responsibility to develop a program which deals mainly with two aspects of the use of the GM products. The first concerns the improvement of the car occupant safety. The second deals with the potential health effects of automotive pollutants.

Obviously, in view of the mandate given to everyone to enforce standards for fuel economy, the corporation had to also resolve the problem if and when it should start with the development of the diesel engine for passenger usage. Obviously, the first thing which was brought to our mind at that time was the expression of a very deep concern about any possible even if not identified, significant adverse health effects which could result from the expanded use of the diesel engine on our roads. It must be emphasized that if a large industry plans to introduce a new product on the road, there is certainly a desire not to produce any short or long term effects on the health of the population.

First thing we did was to review the existing literature. Fortunately, we have been able to identify quite a surprising number of data. At that time, we reviewed all of the literature data in a small publication, which has been released for general use and has also been submitted to the Department of Transportation. I am sure that the department of Transportation will provide you with a copy if you request it.

When we had analyzed and evaluated the literature, we had not been able to demonstrate that there was any evidence of a real significant adverse health effects or hazard.

Obviously, this has some caveats in it. We have identified many data in the literature, most of them originated in the time between 1950 and 1960. However, the medical science has developed since that time. The technology of the diesel engine has also developed. We cannot always apply the conclusions from the published data to all types of engines, to all types of the engine loads or operations, or many other aspects of the wide usage of diesel engines today.

There is an urgent need that a concerted effort should be exerted to provide more data, particularly in the areas where some of our questions could be further clarified.

From this point of view, we are in full agreement with the press release issued by the Environmental Protection Agency on November 12 of last year, where it was declared that at this time, we do not have "sufficient data to make any reasonable estimate of the public health risk, if any, that might be associated with the emissions from the diesel powered engine presently operating on the road." At approximately the same time, the Environmental Protection Agency concluded the first phase of the large study in cooperation with the Southwest Research Institute. Particulate emissions from two heavy duty engines have been collected, extracted, fractionated and tested in a wide variety of the mutagenicity tests. Based on positive results which have been obtained within the study, the EPA felt that they should issue a warning that the diesel exhaust could be potentially hazardous to the public health and nobody should be exposed to diesel exhaust in high concentrations during operation. In particular, it has been recommended that until further data is obtained, diesel engines should not be allowed to idle unnecessarily in enclosed unventilated spaces without the exhaust being vented to the outside air.

This statement had a significant impact on the general public and initiated efforts that the diesel exhaust studies be expanded and use clinical experiments under defined exposure conditions. As you know, whenever anyone wants to use human volunteers, as Dr. Battigelli did 15 years ago, the experimental protocol must be reviewed by an appropriate human research committee and there is no clinical investigation committee which will approve the protocol with this kind of warning today. I feel that the situation should be clarified. If there is a real carcinogenic hazard, then a rapid conclusion must be drawn as soon as possible. If not, the EPA warning should be taken off the record.

With the existing need for further research in the field of diesel exhaust health effects we have initiated activities which practically parallel those planned and executed by the EPA, as we will probably hear from Mr. Blacker in his presentation and I will not go into any further details. Let me only mention briefly that we initiated inhalation studies on animals in cooperation with Wayne State University more than two years ago. We are now evaluating the first two pilot experiments and we hope that, together with the EPA professional staff, we will be able to share with you the results of our studies at the meeting of the Air Pollution Control Association at Houston in June.

We are planning to do more. After two years of concentrated efforts we have just completed our exposure facilities at the General Motors Research Laboratories in Warren, Michigan. We will initiate our own exposure studies probably within the next month or two. We sincerely hope that these studies will generate data that will permit the final assessment of any potential adverse health effects.

On the other hand, we do not want to hide behind caveats, when there is an urgent need to make some preliminary decisions. It is mainly in this respect that I would like to present to you data, which are not so easily available in the literature, at least the first part of it, or which has not yet been in my mind fully evaluated by our colleagues working either as consultants or directly in association with the Federal agencies.

The first activity dates back to 1962 until 1965. At that time, GM Research Laboratories had been working in close cooperation with the Sloan-Kettering Institute, particularly with the group on cancer research. The group did an extensive study analyzing the presence of the polynuclear hydrocarbons in the automotive exhaust and in the air of our cities and correlated it with some other data.

Among the experiments which had been conducted at that time was one experiment which could be of great importance. Unfortunately, since it produced completely negative results and collected data on diesel engine constructed between 1962 and 1965, nobody was too interested in making it a subject of a technical publication. We have found in our old protocols the so far unpublished data and I would like to present it to you today.

May I have the first slide, please?

In cooperation between the GM Research Laboratory and the Sloan-Kettering Institute, diesel exhaust condensate has been accumulated by sequential condensation and filtration from a V-6-71 diesel engine. After that, the condensate was extracted by benzene, separated from the rest of the particulates and distilled in a vacuum. The final product was a sample of diesel exhaust distillate and diesel exhaust tar residue. They were tested by a technique, which was common at that time and it is still used today, called skin painting carcinogenicity testing. Some research institutes in cancer research have developed special strains of mice. After shaving their backs a defined amount of substance which is to be tested can be painted on their skin. Usually, you do it three times in a week or every day and continue for at least one full year. After that, you allow for several months to observe if there is any formation of tumors on the skin of the exposed mice.

A defined amount of the tar distillate was applied three times a week in a group of 50 mice for a period of 52 weeks. The concentration of the distillate in the solvent was about 50 percent and the test continued for 15

SKIN PAINTING CARCINOGENICITY TESTS OF DIESEL EXHAUST TAR AND CIGARETTE SMOKE CONDENSATE
(SLOAN-KETTERING INSTITUTE, 1962-65)

	Concentration in Solvent	No. of Mice	No. of Tumors After 15 Months of Exposure	
			Papillomas	Cancers
Diesel Exhaust Distillate*	50%	50	0	0
Diesel Exhaust Tar Residue*	25%	50	2	0
1960 Cigarette Smoke Condensate**	25%	50	18	2

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* *Wynder E. L., Hoffman D., Begeman C. R., Unpublished data*

** *From Wynder E. L., Hoffman D., Cancer 15, 93, 1962* months. At the end of the experiment, no papillomas or benign tumors were formed on the skin and there was no cancer observed at all.

The same test was done with the diesel exhaust tar residue. If you assume any potential role of benzo(a)pyrene in diesel tar carcinogenesis, it is well known that benzo(a)pyrene and benzanthracene could be found particularly in the tar residue, whereas the diesel exhaust distillate does not usually contain any significant amouns of polynuclear hydrocarbons. Diesel exhaust tar residue was tested in 10, 25 and 50 percent concentration in the solvent. The slide presents only the 25 percent concentration. After 15 months, only two benign tumors were formed and no malignant tumors were observed again. The frequency of two benign tumors is insignificant since there is always a naturally occurring incidence of some benign tumors. Unless the number of tumors exceeds three, the result of the test is classified as insignificant.

In comparison with the diesel tar tests, I have included data dealing with the 1960 cigarette smoke condensate and produced by the same group in the year 1962. At that time, medical and scientific community was interested in proving or disproving if cigarette smoking is responsible for the higher incidence of the lung cancer in smoking populations. Today, it is generally accepted that the risk of a heavy smoker dying from lung cancer is increased when compared with the non-smoking populations. The skin painting experiment corroborates the evidence. As you can see a concentration of about 25 percent condensate produced about 18 papillomas and two cancers in this simple test.

Again, I do not want to declare that this is the final test. First, it does not apply to all engines. In addition, it does not apply to all loads and road conditions. However, when there is an urgent need to decide about the expected impact of wider use of diesel engine it makes you a little happier if you can see that the carcinogenicity has not been experimentally documented.

Obviously, we are planning to do more of this testing. But, as you can see, we had to wait at least for one and-a-half or two years before any results could be put on the record.

This is important particularly for many of the people who have read the EPA statement. Since they are concerned about the potential relationship between the positive results of the mutagenicity and the carcinogenic effects. Let me just tell you that in the first phases of the development of the so-called Ames test we have had the data which indicated that at least in one group of carcinogens there was 85 to 90 percent positive correlation demonstrated between the mutagenic and carcinogenic effects. Since that time more data has been accumulated. It was particularly the Cold Spring Harbor Conference last fall and the work of a group of Japanese authors, which has later been confirmed also on our continent, that indicated that the correlation is not as high as originally indicated. The expected general correlation of only about 45 or 50 percent, indicates that there are types of carcinogens which have a good correlation with mutagenic effects and that there might be some other group of carcinogens where the correlation of both effects is not so significant.

I am just quoting a statement which was mentioned during the recent Environmental Health Advisory Committee meeting of the Science Advisory Board of the Environmental Protection Agency, where even the members of the agency's own advisory board, admitted and indicated that the original enthusiasm over the Ames' test as an optimal screening test for carcinogenicity probably needs to be reviewed today.

As I mentioned previously, there are many caveats in any experimental proof of carcinogenicity. First, there is a question if the Ames' test, done on very primitive organisms without as much possibility of DNA repair as the mammalian cells can be extrapolated to the human situation.

We would like to depend more on data accumulated on the human populations exposed to diesel particulates. If you search for this type of data in the literature, you can find that there are at least four studies which can be mentioned and all of them reported negative results. Particularly one study is worth mentioning, since this is the single study where the exposure has also been measured. It is the study of the Medical Research Council in London, briefly mentioned by Dick Wheeler this morning. Again, I would like to review with you just some of the data.

Next slide, please. #2

The study was done in the year 1956 to 1957 in cooperation with the London Transit System. It dealt with potential exposure of their staff to diesel fumes in the garages of the London buses. The Medical Research Council measured the smoke concentrations in these garages in four periods of the day. The three important periods are presented in the slide.

The first period was between 6:00 p.m. and 11:00 p.m. when the buses were returning home and were left in the front of the garage. Later on, they were taken one by one for refueling and washing inside of the garage. This resulted in an increase of the smoke concentration inside in comparison with the outside. As you can see, the values outside varied between 200 and 900 micrograms per cubic meter. In the garage, they were increased from 500 to 1,800 micrograms per cubic meter. The four numbers represent repeated measurements done in April, June and October 1956 and again in April 1957.

The period between 11:00 p.m. and 1:00 a.m. was the period of the most active vehicle transport in the garages, when most of the vehicles have reached the refueling station and the washing station. As mentioned by the authors, the vehicles have been usually left there idling all the time. This resulted in a considerable increase of concentration up to the 1.4 or three milligrams per cubic meter.

CONCENTRATIONS OF PARTICULATES AT TWO LONDON TRANSPORT GARAGES AT VARIOUS TIMES OF THE DAY AND YEAR (APRIL, JUNE, OCTOBER 1956)

	Smoke Concentrations $\mu g/m^3$			
Period	Outside		Garage	
6 P.M. –	240	260	550	810
11 P.M.	640	920	900	1800
11 P.M. –	120	140	260	270
1 A.M.	230	1460	1440	3040
1 A.M. –	60	70	80	140
5 A.M.	180	660	210	770

From: Commins B.T., Waller R. E. and Lawther P. J.: Brit. J. Ind. Med. 14:232, 1957

In comparison, the period between 1:00 to 5:00 p.m. was a period when there was practically quiet in the garage and where the concentrations inside have again been commensurate with the outside.

Next slide, please. #3

The London Transit System has a very excellent medical record file. Therefore, it was possible for the Medical Research Council Staff, together with the medical staff of the London Transit System, to extract data on the potential effects of exposure expressed on the slide in man-years. For example, in the terms of the garage staff, which was of the largest interest to us since this is the area where the concentrations were measured, the exposed cohort represented more than 18,000 man-years. When compared with the occurrence of death, ill health, retirements and transfers to alternative work due to the health problems or due to lung cancer, the authors have not been able to identify any higher incidence of these effects in the exposed groups. Among the garage staff, out of 22 cases of all recorded effects, there resulted 21 deaths. When this is expressed as an annual rate per 1,000 employees, it is reflected at the level of only about 1.2. When compared with the data collected at about the same time in England and in the Greater London area, you can find annual rates in the general population which are not significantly different from those of the exposed group. In absolute terms, they are even a little lower than in unexposed population.

Again, it is only one incidence in the literature. I have been very pleased to hear from the Environmental Protection Agency staff that among their research programs on health effects they are considering to initiate a program in epidemiological studies, which will probably be at least as significant as this study from Great Britain. But for the time being, I would like to conclude with a statement which you can read . . .

DEATHS, ILL-HEALTH RETIREMENTS AND TRANSFERS TO ALTERNATIVE WORK DUE TO LUNG CANCER DURING 1950–54 IN LONDON TRANSPORT BUS MALE OPERATORS, AGED 45–64

Group	Exposure (Man Years)	All	Deaths	Annual Rate Per 1,000
Bus Drivers	33,466	23	17	0.7
Bus Conductors	16,978	18	15	1.1
Garage Staff	18,140	22	21	1.2
General Population:				
England & Wales	19,947,000	–	26,689	1.3
Greater London	3,834,000	–	6,292	1.6

From Raffle P.A.B.: Brit. J. Ind. Med. 14: 73:1957

(Next slide, please.) #4

. . . in the reports and publications which I have just quoted. It is a statement by Dr. Raffle, who has been in charge of the health effects evaluation of the English investigators. He says, "All that can be said on the basis of the small figures so far available is that there is no excess of lung cancer among any group of London Transport staff such as would have been expected if diesel exhaust fumes were a serious contributory factor in producing an excess of lung cancer in urban city dwellers."

Again, there are some caveats in it. I would completely endorse a statement of any member of the audience that this is not yet the final word. We would like to have more data on record. But, for a general decision, if we could realistically accept an enlargement of the diesel engine use on our roads, this is giving us at least a little better feeling.

Thank you.

(Applause.)

> ". . . all that can be said, on the basis of the small figures so far available, is that there is no excess of lung cancer among any group of London Transport staff such as would have been expected if diesel exhaust fumes were a serious contributory factor in producing an excess of lung cancer in urban dwellers."

Raffle P.A.B.: Brit. J. Ind. Med. 14, 73, 1957

DR. MILBY: Thank you, Dr. Vostal.

Indeed, you are correct. I have gotten things a bit out of line here. I wrote notes on my own copy of the original agenda, and I have been using that. I hope I have not discommoded Dr. Blacker or Dr. Barth, whoever is going to make that presentation.

Is Dr. Blacker here?

While Dr. Blacker is coming up here, I want to be sure that we get everybody in, because there are several who have airplane problems. Dr. Crowley is still okay. So, I would not want to get him too far out of line. While Dr. Blacker is coming up, I would like to make a comment on this slide that we saw, which Dr. Vostal showed us. I would like to remind you of the healthy worker effect. If one were to examine the death rates in a working population versus a general population, one would expect to see a difference based on the healthy worker effect. So, while I have seen Dr. Raffle's work, and I think it is very impressive, I think one needs to keep that in mind.

DR. BLACKER: What I would like to talk about today is the Environmental Protection Agency's Health Effects Research Program on Diesel Exhaust Products. I work for Dr. Barth, who is the Deputy Assistant Administrator for Health and Ecological Effects. I coordinate the health research program in the diesel area and in other mobile source areas conducted principally at our two laboratories, one at Cincinnati, Ohio, and the other one at Research Triangle Park in North Carolina.

The program that I would like to focus on today is that which we are doing on diesels. It is broken up into three major research areas. The first one is in vitro screening. The second one is whole animal exhaust work. The third is epidemiology.

I will briefly describe what research we have, are, or will be, conducting in each of these areas; but I will not be discussing any results of these studies that have been conducted because this is not the intent as I understood it, of this session, nor do we have many results at this point.

By the end of June, 1978, the health group will be presenting all of its available data. However, the data which will be presented around July 1 will merely be the results of a range finding basis and will not be providing even a minimal data base for any definitive conclusion concerning potential public health effects, if any, that result for diesel exhaust products. It will take a few more years to provide that complete data base as a final conclusion.

I would like to go into in vitro screening work right now. Through the strong support of a sister laboratory, the Environmental Sciences Research Laboratory at RTP and Dr. Ron Bradow of that laboratory, we obtained particle samples from diesel exhaust products that were cooled to 120 degrees Fahrenheit before they were collected on a filter. The engines that provided the particulate were two-stroke cycle engines typical of city buses and a four-stroke engine used in urban service vehicles.

Dr. Bradow separated the organic extract of the particulate into seven fractions of chemically similar constituents. Then certain of those fractions were introduced into the Ames Salmonella microsome mutagenicity assay. We obtained positive results in several of the fractions. This was reported to the public in EPA's Environmental News Release of November 12, which Dr. Vostal referred to in his talk.

Dr. Barth presented some follow-up comments on November 28 in New York City. Those comments are also available and have been sent out to those people who were interested in follow-up information.

We are using in vitro screening systems like the Ames system and other more sophisticated systems for two principal reasons. The first concerns the work that Dr. Bradow is doing. Dr. Bradow estimates that there are many thousands of organic compounds that are adsorbed onto the particulate. He is using this in vitro screening system to assist him in identifying those fractions that are biologically active so that he can undertake focused characterization studies to identify which specific species are causing the biological activity that we are seeing in these screening tests.

Secondly, screening systems are used to indicate which possible adverse health effect end points we should be focusing on to concentrate our whole animal studies and our epidemiology studies.

I would like to emphasize one important point. All of the in vitro screening work that we are doing and conducting is only used to set priorities for what whole animal experiments we would like to do and should conduct. It will be the whole animal experiments and the epidemiology along with the in vitro screening studies as an adjunct which will be the principal basis for any conclusions we draw on whether there is any health consequences that may result from diesel exhaust products.

In the in vitro screening area, we would like to do the following studies, in addition to those we reported in the news release of November, 1977, plus what was reported at the Williamsburg Conference in late February, 1978, of which a paper is being prepared right now and will be, hopefully, available in the next month or so for distribution. There are approximately seven or eight different series of studies that we are doing in the in vitro screening area.

We are going to continue to introduce particulate samples provided by Dr. Bradow's operation, provided the mobile source people in Ann Arbor and by contractors into the Ames system to identify which samples, organic extracts, and fractions thereof, show biological activity in the Ames system. Those samples or fractions do show biological activity will most likely be introduced into confirmatory in vitro test systems to measure mutagenicity, carcinogenicity, and cytotoxicity. We are also going to be developing new techniques for further evaluating the diesel particulate.

For example, the Cincinnati work that we are conducting now, we would like to try to take the deposited particulate directly out of sacrificed animal lungs and take that particulate and introduce it into the different in vitro screening systems to see what kind of results we get. However, the techniques are not yet available to immediately introduce those particulates; and we are going to have to do some more developmental work in that area.

We are also going to try to use the in vitro screening test to identify variations in diesel exhaust samples in biological activity as a function of engine type, fuel burned, and driving schedule. We are also going to try to collect ambient samples around roadways to measure the roadway contribution to the particulate and see what kind of biological activity, based on the in vitro screening test, we see from the roadway particulate. Some of that work is now going on in the Los Angeles area on the Los Angeles catalyst study site along the San Diego freeway.

We are also in the process now of doing some skin painting work with the particulate that was obtained for the last November news release information. That information should be available in several months. We just introduced the material into the skin painting system in the last week or two.

The second major area that I would like to talk about is the exposure by way of the inhalation route of whole animals to diluted whole exhaust from diesel light duty engines. This work is conducted principally at our health effects laboratory in Cincinnati and to a smaller extent at our health laboratory at Research Triangle Park.

In Cincinnati, we have an engine dynamometer stand holding a six-cylinder Nissan engine. We have completed back in mid-December a 50-day pilot study using this Nissan engine and several species of animals. Because there has been very little reported on the effects of animals exposed by way of the inhalation route, this pilot study was intended to define for future studies the likely biological endpoints to consider. Therefore, a wide variety of biological parameters were measured. These include pulmonary function testing, increased susceptibility to respiratory infection using the infectivity model that was developed earlier with streptococcus, semi-quantitative deposition and clearance of particulate entering the lung, lung and otherpathology, biochemical changes in the lung, and other tissues, pulmonary tumor development in special strain and normal animals, lung changes for indication of fibrosis and emphysema, and changes in behavioral activity.

Certain of these experiments were of short duration, that is, a couple of days or a week. Others were of much longer duration, several weeks. As I said before, this was a total of a 50-day study.

The results of this pilot study are now being compiled and will be available in the late June or July time frame. Sometime during the summer of 1978, we intend to start the next set of whole animal exhaust studies. In the next set of studies, we would like to conduct several acute, sub-acute, and chronic studies simultaneously.

During this next set of studies, we plan to focus on those previously mentioned parameters that gave us useful and important data and, also, consider the following parameters, changes in lung immunocompetency, transplacental carcinogenicity, implant carcinogenicity, cytogenetic effects in lung cells, and teratology and perinatal development effects.

In our Cincinnati facility, we are only limited to one engine, one fuel, and one driving cycle. The parameters that Dr. Bradow indicated have a major effect on exhaust products. We have had to consult closely with him in selecting the most reasonable parameters to use during this testing. This selection will be expecially critical in the next set of experiments that we plan to conduct beginning in the summer of 1978.

To complement the in-house work, we would like to perform a similar set of whole animal exhaust studies by contract. The contractor will use a different engine, a different fuel, and a different driving cycle, so that he can compare results. In this way, he will have more data and a broader confidence in assessing what health risks, if any, may result from large scale introduction of many types of diesel power systems in this country.

In this whole animal exposure work, we are also doing some additional studies that do not look at the whole exhaust. We are in the process of trying to quantitatively determine the location of deposition in the rate of clearance in animals of particulate that simulates that of diesel particulate. We are now developing and, hopefully, will have in our laboratory very soon in North Carolina, a propane burner.

Once we have a data base on deposition and clearance rate, we hope to adsorb onto the carbon particulate generated from this propane burner generator the principal toxic components that are found on diesel exhaust identified by Dr. Bradow's and Dr. Huisingh's work in North Carolina in the in vitro screening area. We want to measure how the rates of deposition are affected and how clearance rates are affected when the toxic organics are placed on the particulate.

We also want to measure the amount of organics that are desorbed from the particulate, if we can. Another set of experiments we want to conduct is exposing whole animals bv the inhalation route to principal toxic organics that we identify from Dr. Bradow's and Dr. Huisingh's work and see what kind of biological end point we can identify and what kind of results we get from those exposures.

The third major area of research is epidemiology. Although we have not started any field studies to date, we have been investigating the desirability of joining onto some of the studies that are being conducted by NIOSH, especially the study of the mechanics of locomotive roundhouses. One major concern we have in piggybacking on any of the NIOSH work, however, is whether the composition of the exhaust products and the atmosphere that the workers are exposed to are similar enough to those that the public in general would be exposed to from significant introduction of diesel powered vehicles. We are now investigating this situation.

We are also searching for existing populations to conduct morbidity studies, and we would like to perform some mortality studies. We are now in the process of developing a detailed plan for conducting this epidemiological work and hope to have a plan finalized in the next couple of months in this area.

We are trying to take the data from all three areas, the in vitro screening, the whole animal exhaust and the epidemiology, put it all together and come up with some reasonable estimate of whether we expect there to be a public health problem, if any, from diesel exhaust products. We would like any cooperation from the outside community in helping us focus in on what end points we ought to be looking at and providing us with complementary experiments so that in a very short period of time we can have all the answers as to whether there are any health problems associated with diesel exhaust products.

Thank you.

DR. MILBY: Our next speaker will, again, be out of turn because of airplane connections and that will be Dr. Crowley.

DR. CROWLEY: Thank you very much. I had planned, when I saw the flyer on this meeting, to attend as an observer. I was involve in a site visit to the group at Oak Ridge. I cam back and found out I was giving a presentation.

The title says, "Comprehensive In-Vitro Bioassays Profiles." That is a bit presumptuous on our part. It is not comprehensive, as you know. There are certain systems which are more accepted than others; but people doing active research in the area know that there are so many different complex, genetic, regulatory factors still not elucidated. There is not one system on an in vitro basis that is going to answer our questions.

The in vitro system does offer a screening profile to provide a data base to make decisions to go and make further studies in either intact animals or epidemiological based studies. We are currently involved in doing activity directed fractionation studies with particulates, not diesel particulates. These are fly ash particulates. We are using the Ames system.

Not having seen the agenda, I did not bring that information. It is the same type of study that you have seen. We have active fractions and non-active fractions in the Ames system. Rather, I brought pretty much last week's data out of a book on showing some of the other tests that we use on a profile basis with full realization that (1) we are in a sense trying to comply and carry out the Level I type of test in the EPA manual, (2) we are trying to add on other tests which we feel will expand the information base but are not in the manual, and (3) while doing all this, we are trying to comply with GLP, which has gone into force this last January where all the procedures must be thoroughly documented. But, as working scientists, we know that the procedures continually subtly change. It is a problem of at what point is a major change noted. It is a very complex problem that Dr. Vostal brought out earlier about the Ames.

Now, I talked to Dr. Belcher at the Williamsburg meeting, with whom Dr. Pitts has worked in collaboration. We had an ad hoc meeting attended by approximately 70 people just on the Ames system well into the night. We came out with about 10 different major areas that are subject to the individual variation between laboratory and laboratory.

Now, there are studies being funded now by NCI to further define and characterize the system, but these are some of the problems that the private sector has and also the regulatory agencies have. How do you pick these tests? Which tests do you pick? There has to be some level of uniformity within certain limits. It is a very complex problem, but it can be done. In clinical chemistry, for instance, the clinical laboratories have standard internal and external tests to make sure that the different laboratories and the hundreds of hospitals across the country do give out reasonable results that fall within defined limits. So, it is a problem; but it can be solved but amplified with all the other problems that you gentlemen have been addressing yourselves to today up to the problem of health effects. I do not want to seem like I am throwing out more problems, but there are a lot of problems just in determining true health effects.

As I said, my background is primarily cell biology and mammalian tissue culture; so that is my interest, but I will try to give you a very brief profile effect of a typical system that we do with particulates. These are fly ash. They are both coal based and oil generated materials.

May I have the first slide, please? #1

This is some work that was done by the group in 1976 and is based on automobile emissions with gasoline engines. It was done by GC mass spec. As I said, we are now doing organic extraction and HPLC activity directed fractionation studies. This system is a tissue culture system using BALB/3T3 cells.

Next slide, please. #2

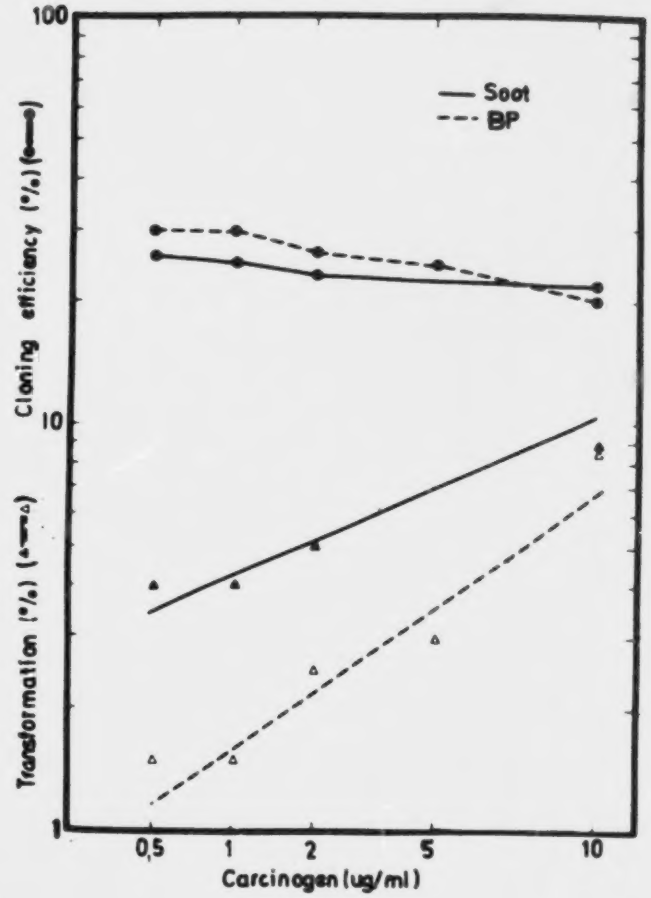
This is a typical dose response curve that was generated by that study. The upper curves are cytotoxicity as represented by cloning efficiency. The hatched curve is a control. The solid line is an extract of the exhaust emission.

We no longer use these cells in a transformation system. This is approaching one of the problem areas. These cells have been used and studied extensively. However, they really do not provide a very sensitive tissue culture transformation system. They have a very high spontaneous transformation rate. It is too high to catch or monitor either complex mixtures or pure chemicals that might have weak carcinogenic effects. So, we no longer use this cell system.

Polycyclic aromatic hydrocarbon	Carcinogenic activity[a]	Percent of extract
Anthracene	-	0.01
Methyl anthracene (2 isomers)	+	0.004
Pyrene	-	0.02
Fluoranthene	-	0.02
Methyl pyrenes or fluoranthenes (4 isomers)	+	0.004
Benzanthracene	++	0.002
Benzfluorene (4 isomers)	++	0.01
Benzpyrene or Benzfluoranthene (2 isomers)	+++	0.002
Methyl benzanthracene	+++	0.004
Methyl benzfluorene (4 isomers)	++	0.002
Aceanthrylene	-	0.004

[a] Degree of carcinogenicity from negative (-) to strongly positive (+++). (Data derived from work of others.)

Transformation of Nonvirus Producing BALB/3T3 Cells by an Environmental Extract*



Transformation of Nonvirus Producing BALB/3T3 Cells by an Environmental Extract*

Next slide, please #3

This slide makes use of a system that we utilize, but it has its own problems. It is an E. coli system in which an organism has a polymerase deficient genetic make-up. In other words, it has an enzyme deficiency that renders the organism unable to repair DNA.

If you will notice, in this system you evaluate the effect. You pulse the organisms with the chemical, or whatever, that you are interested in. The way this has been scored, you pulse the polymerase deficient organism along with a wild type organism.

Thsi is a spot test, and it has a lot of problems with it; but it is very quick. We usually run it as an adjunct to the Ames just to see what kind of answers it gives.

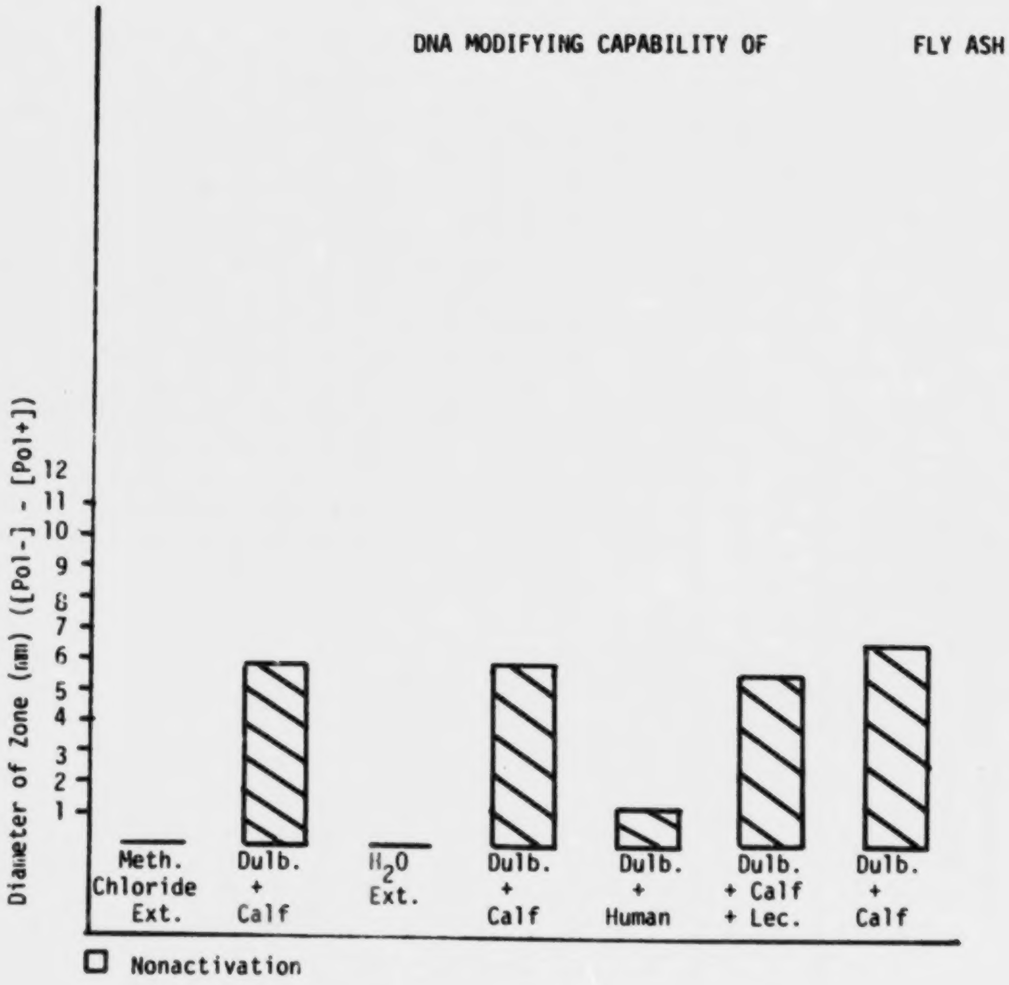
If you see a preferential killing of the organism that has the repair deficient mechanmism, the compound is interacting with either the DNA or some system connected with the DNA. Therefore, it has possible mutagenic effects.

In this particular fly ash, we saw no effect. That should be a cyclohexane extract. However, we incubated or extracted, if you will, the particular fly ash with tissue culture media containing calf serum, which is called complete Dulbecco. It has 10 percent calf serum. We extracted with water, and we extracted with the tissue culture media with human serum, and then, the Dulbecco plus calf serum and lecithin to mimic a lung surfactant system. We found definite mutagenic effects in this system.

This particular fly ash did not generate a positive Ames. Now, we have gone back and are rerunning with Ames since, again, this is a spot test. It has problems with the activation systems in it, but we found these interesting results, and we also found another result, the mutagenic effect associated with just the calf serum. You will notice neither the water extract nor the solvent extract, which should be cyclohexane extract, exhibited any effect. Now, we carried this particular fly ash through another series of tests, which I will go through very briefly.

4/4/78

DNA MODIFYING CAPABILITY OF FLY ASH EXTRACTS



Next slide, please. #4

This is with a different fly ash sample. This is an oil based fly ash. The other one was a coal based fly ash. We found some effect, but not nearly as noted with the previous sample.

Next slide, please. #5

Here we tried another sample using activation/non-activation system. As I say, this system does show some problems. However, with this sample, we did get positive Ames, along with, as you see, positive results in this test. But the results were more or less across the board with the water extracts, the tissue culture incomplete Dulbecco's extract and the complete, in other words, the calf serum containing extract.

Next slide, please. #6

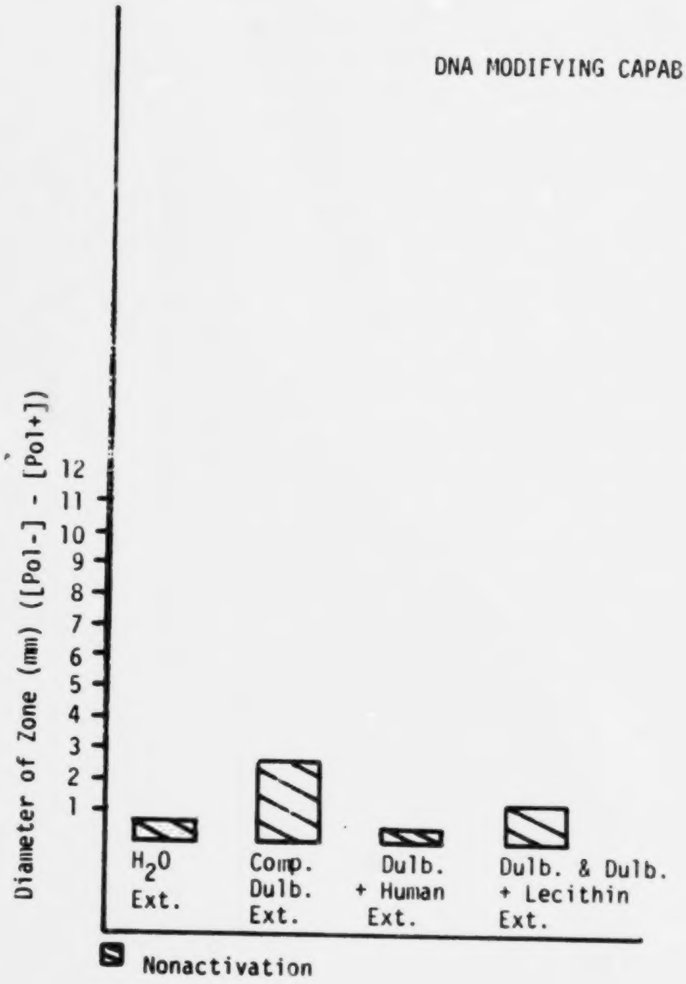
In the evaluation of these materials, using mammalian cells systems, we use a type of cytotoxicity assay that was developed in our laboratories just as a screening tool to delineate effective concentrations for use in transformation assays and DNA repair assays. So, we get some idea of what dose levels to use. The results or any effects are not masked by gross cytotoxicity, which has been shown to take place by mechanisms other than carcinogenesis.

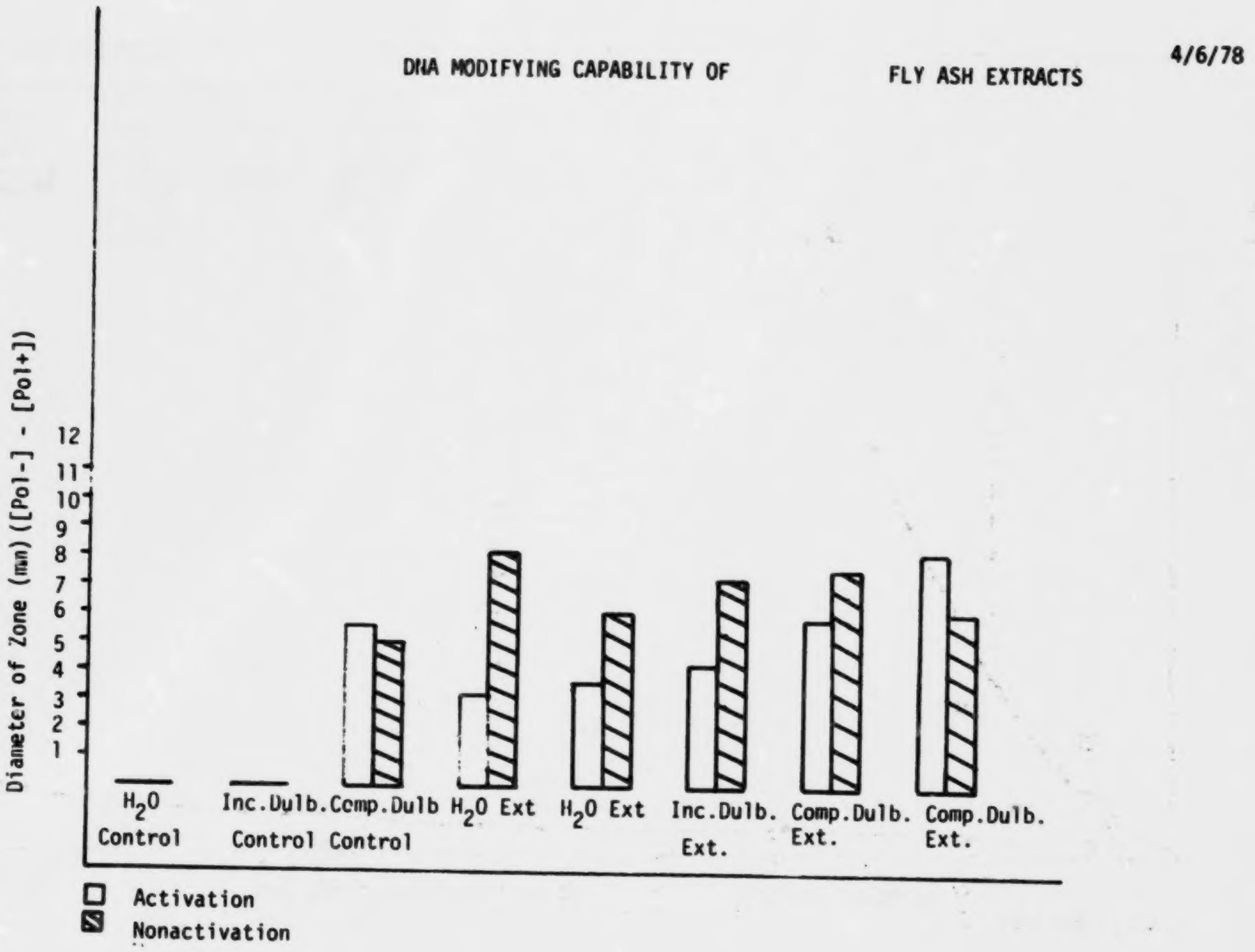
These are the results, again using 3T3. This is an old slide that I already had. We used 3T3's of two different fly ashes. As you can see, they exhibit quite different results. These materials would then be used in various concentrations in a DNA repair system, using lung fibroblast, WI-38's. The standard transformation cell system that we now use is a C3H 10T 1/2.

Next slide, please. #7

Again, this is human embryonic lung cells, WI-38's. With any respirable particulate, we use a profile of cells; the WI-38's being one of them. This is a typical dose response curve using the pre-screen confluence (?) the assay. The reason I make that differentiation is there are some cytotoxicity assays that we use with the these cells that are forwarded in the EPA Level I manual but are

DNA MODIFYING CAPABILITY OF FLY ASH EXTRACTS 4/4/78



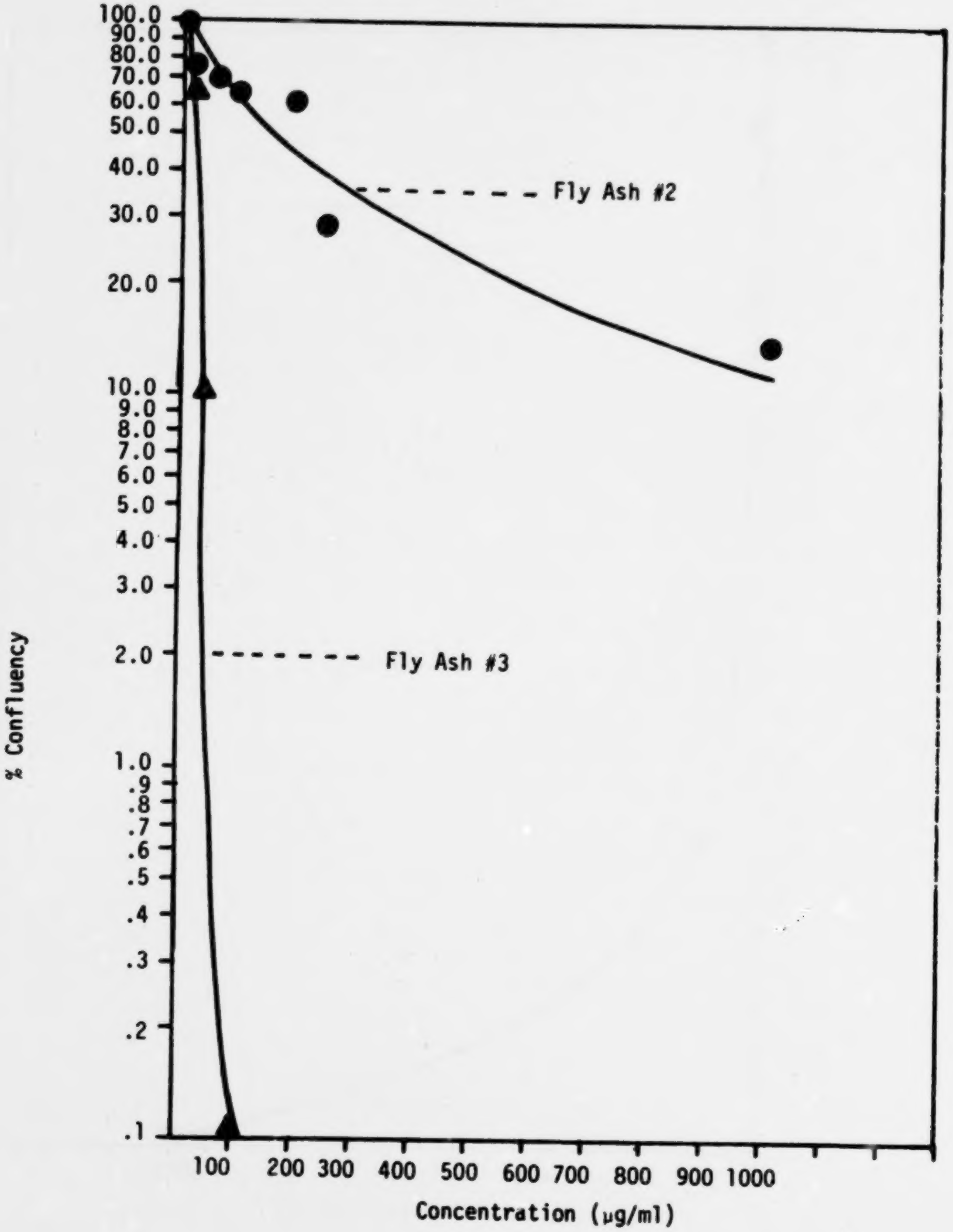


DNA MODIFYING CAPABILITY OF FLY ASH EXTRACTS

4/6/78

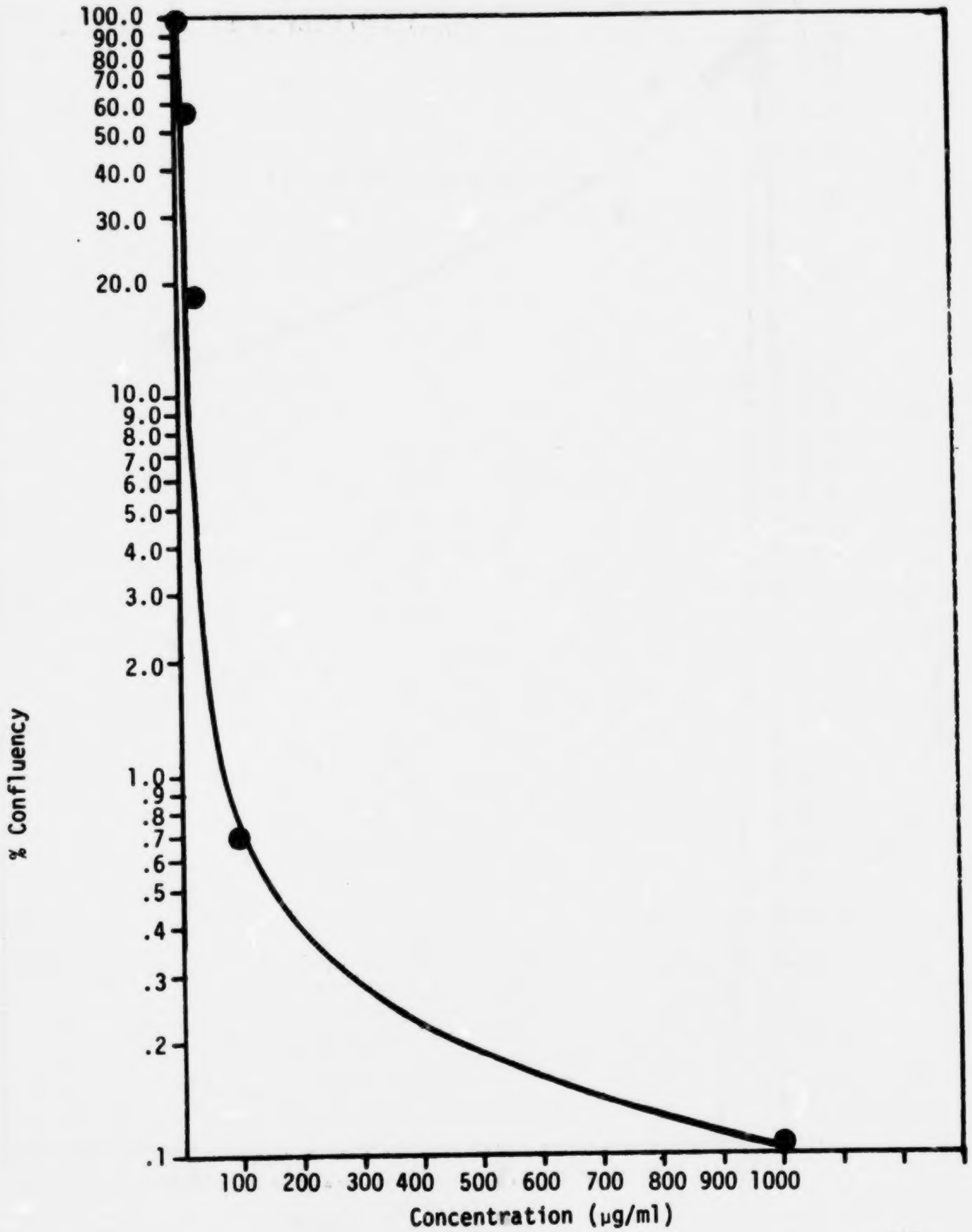
CYTOTOXICITY (PSC) IN 3T3A31C1 7 CELLS EXPOSED TO FLY ASH HORSE SERUM EXTRACT

CROWLEY - 6



CYTOTOXICITY (PSC) IN WI-38 HUMAN EMBRYONIC LUNG CELLS EXPOSED TO FLY ASH - DULBECCO'S (COMPLETE) EXTRACT.

CROWLEY - 7



carried out in a different manner and take into effect different portions. So, this is a cytotoxicity assay based on surface attachment. The others are based on other parameters.

Next slide, please. #8

Again, this is the same profile. The other one was a water extract. This is an extract with tissue culture media, Dulbecco's with calf serum. Interestingly enough, based onrour previous year's work, we have seen many of our positive results, or interesting results, in mammalian cells systems have been found with these aqueous based extracts, not organically based extracts.

Next slide, please. #9

Here is one we pulsed with particulates that were sized. I say sized, that is a crude sizing. When so many samples are brought in, they have to be physically ground up; and then I have the people run them through a sieve series. These were put through a 38 micron exclusion. It is a very rough sizing, but it is something that we must do in the laboratory to decrease our variance and insure reproducibility.

Next slide, please. #10

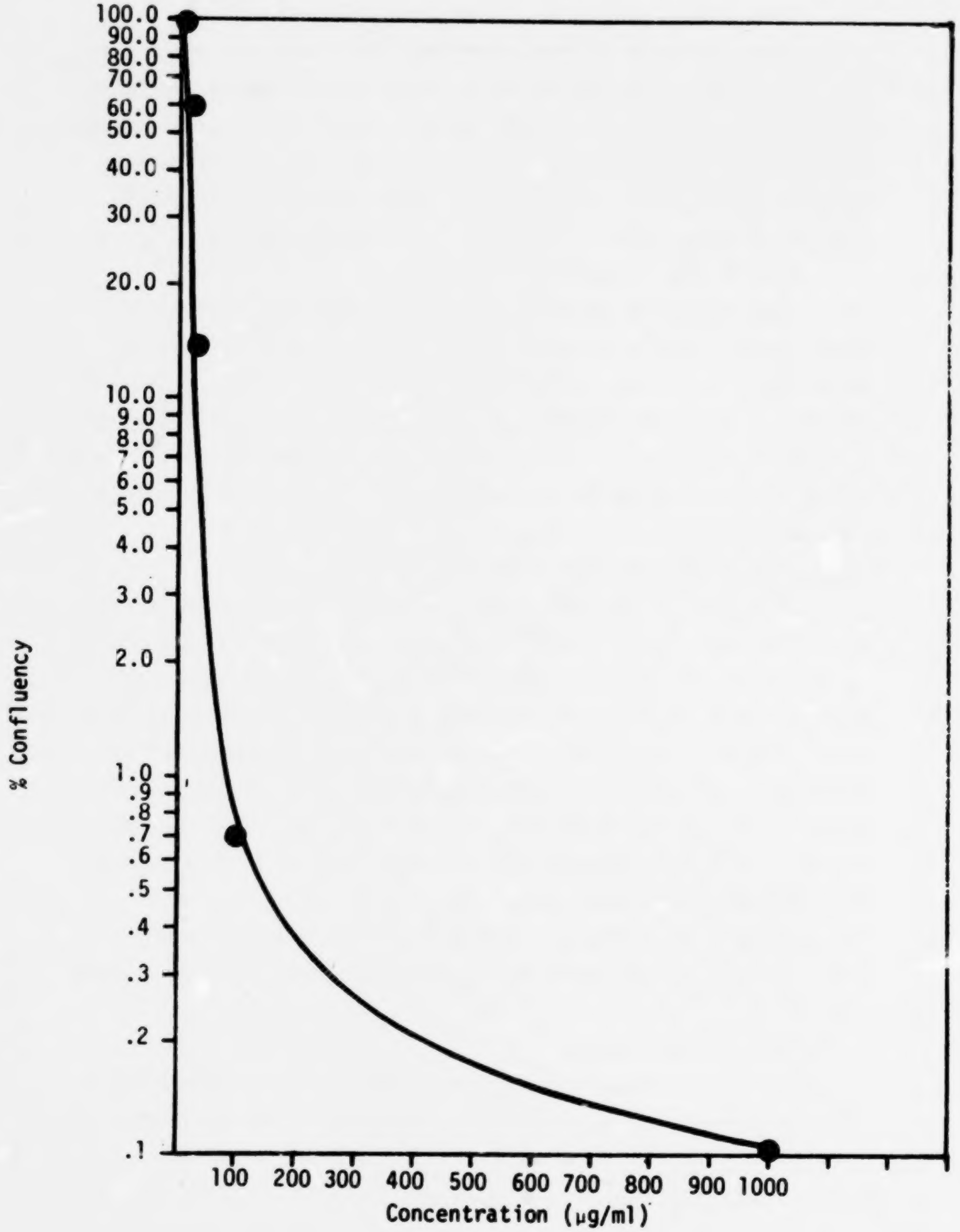
Again, these are not extracts. These are rabbit alveolar macrophages. This is the RAM test that is part of the Level I cytotoxicity assays that is used for any respirable particulate, heavy metals. Mike Waters has done a lot of nice work with this assay. This is as a result of exposure to particulates and its viability. It is done by tripan blue exclusion, which has certain problems inherent with it; but, with these cells, they are easily acquired. It is a primary cell, whereas, the WI-38's have been carried in passage many times. So, therefore, the academic argument can be, well, the cells are really different than they are in the body, which, in fact, they are in studying membrane receptors and what not.

Next slide, please. #11

Another parameter that is done with the alveolar macrophages is total protein along with total cell counts. Sometimes they

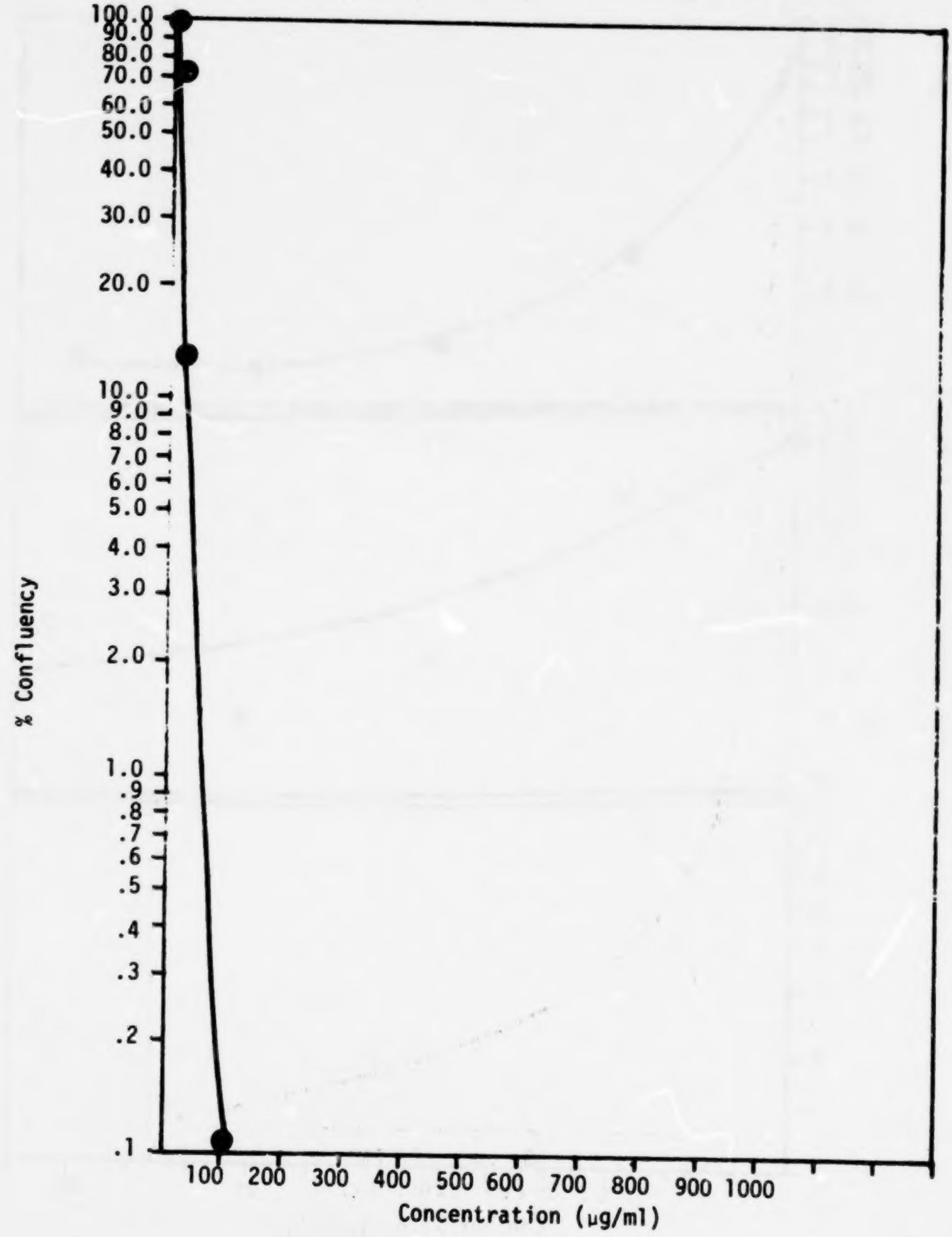
CYTOTOXICITY (PSC) IN WI-38 HUMAN EMBRYONIC LUNG CELLS EXPOSED TO FLY ASH - WATER EXTRACT.

CROWLEY - 8



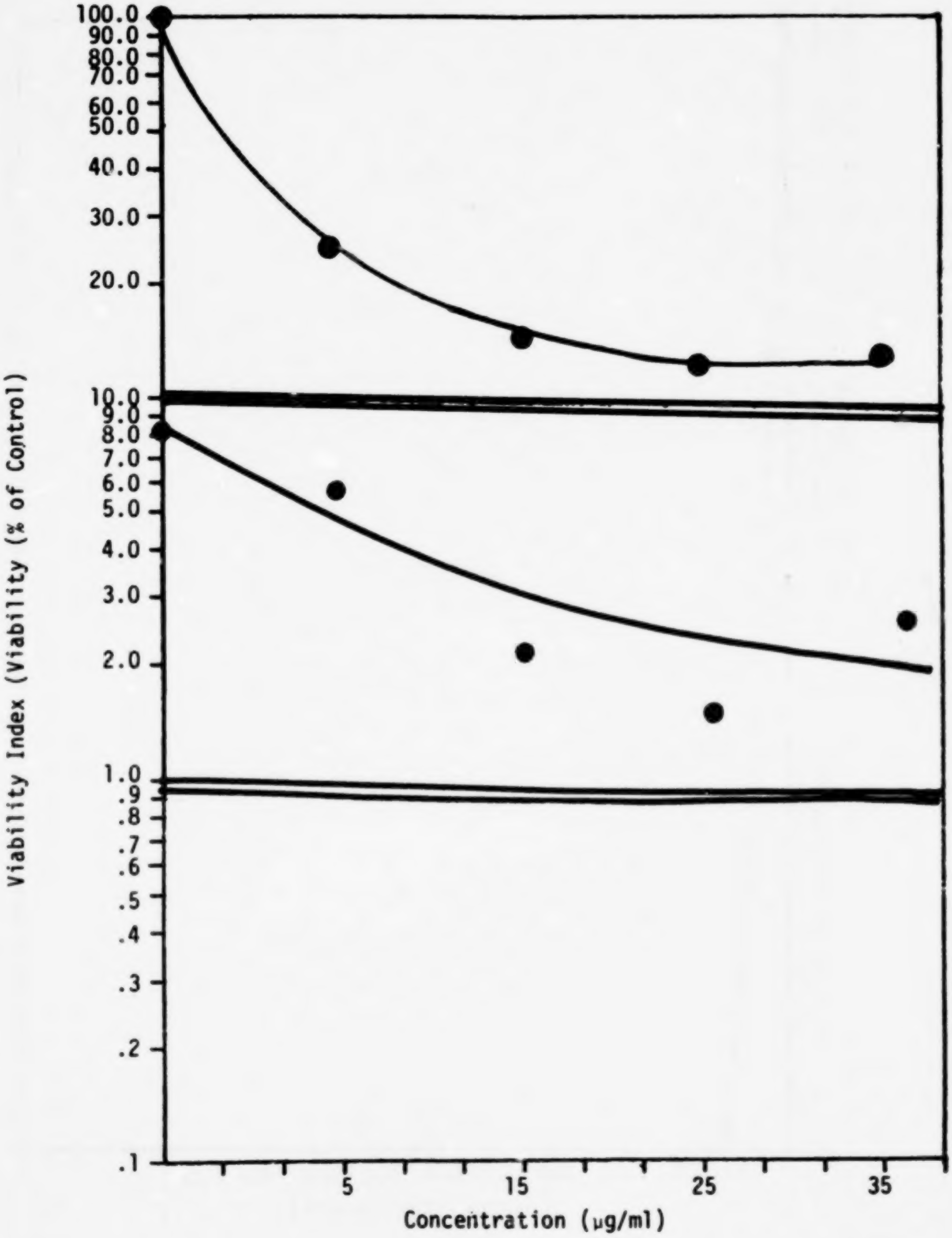
CYTOTOXICITY (PSC) IN WI-38 HUMAN EMBRYONIC LUNG CELLS EXPOSED TO FLY ASH PARTICULATES

CROWLEY - 9

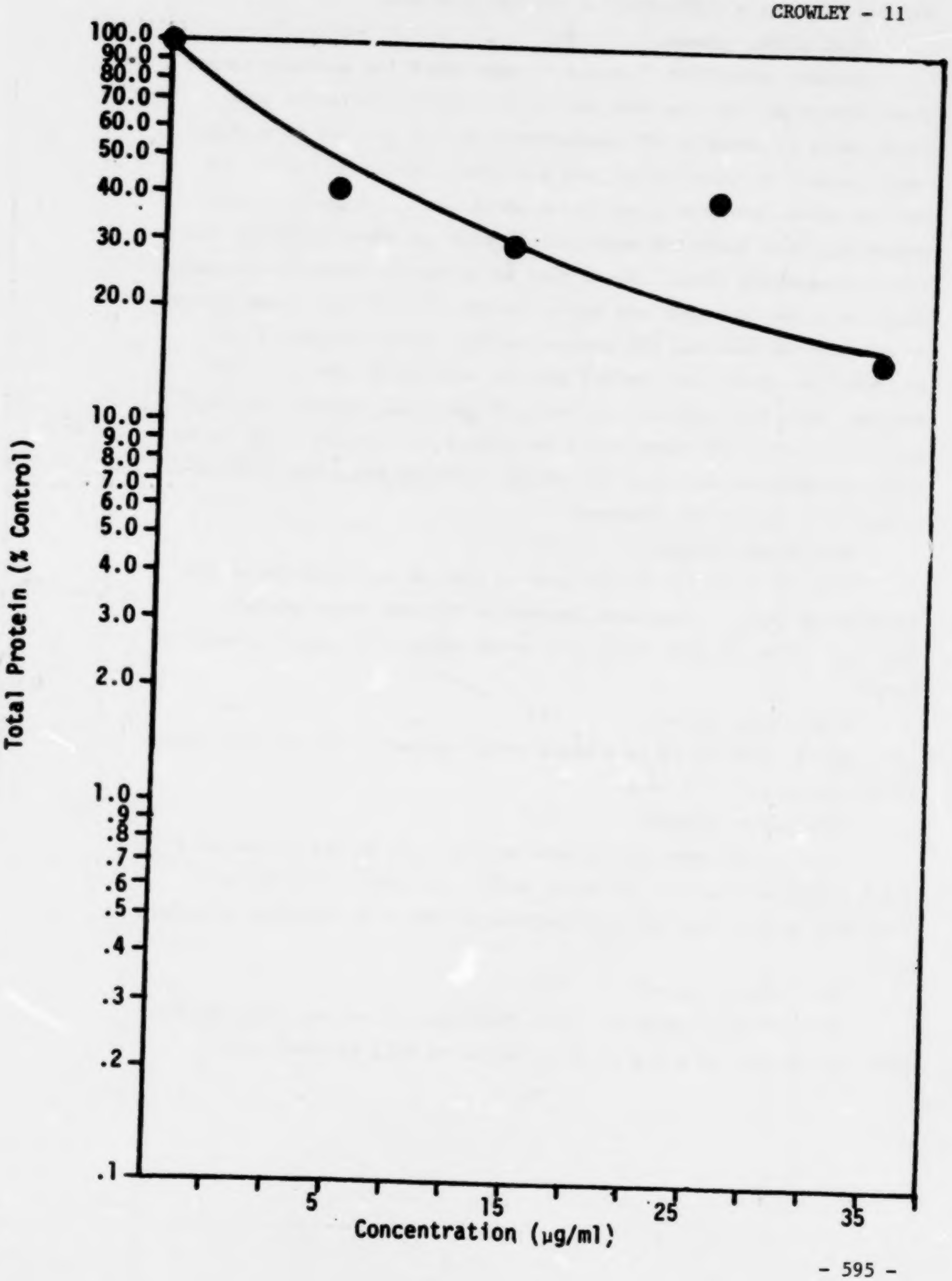


CYTOTOXICITY IN RABBIT (NZW) ALVEOLAR MACROPHAGES
EXPOSED TO FLY ASH - DULBECCO'S (COMPLETE) EXTRACT.

CROWLEY - 10



CYTOTOXICITY IN RABBIT (NZW) ALVEOLAR MACROPHAGES EXPOSED TO FLY ASH - DULBECCO'S (COMPLETE) EXTRACT.



parallel, but sometimes you get a compound that will not appreciably affect cell death but will dramaticaly affect protein synthesis. So, you will see a difference in the two profiles.

Next slide, please. #12

Another point that I wanted to make about the alveolar macrophage system is that the most sensitive toxicity indicator with these cells is probably ATP concentrations. Or you can do a phagocytic index. In other words, you get a base number of cells, and you can pulse them with sized latex particles for a specific time period and then score how many cells ingest and then normalize that into a phagocytic index. Since this is an energy dependent process, there is a simple method now using luciferin luciferase based system to measure the internal ATP concentration. Unfortunately, I did not have any slides nor could I get one made up in time for this meeting; but, for instance, in terms of the total protein for that particular test, the curve would be quite a bit steeper. So, it is quite a sensitive indicator of initial toxicity resulting from exposure to a particular compound.

Next slide, please. #13

This was a series of the Level I type of cytotoxicity assays using WI-38 cells. They were exposed to fly ash water extract. The first curve is just total cell count after the proper incubation period.

Next slide, please. #14

Again, this is protein using water extract. You see the curves there are exactly the same.

Next slide, please. #15

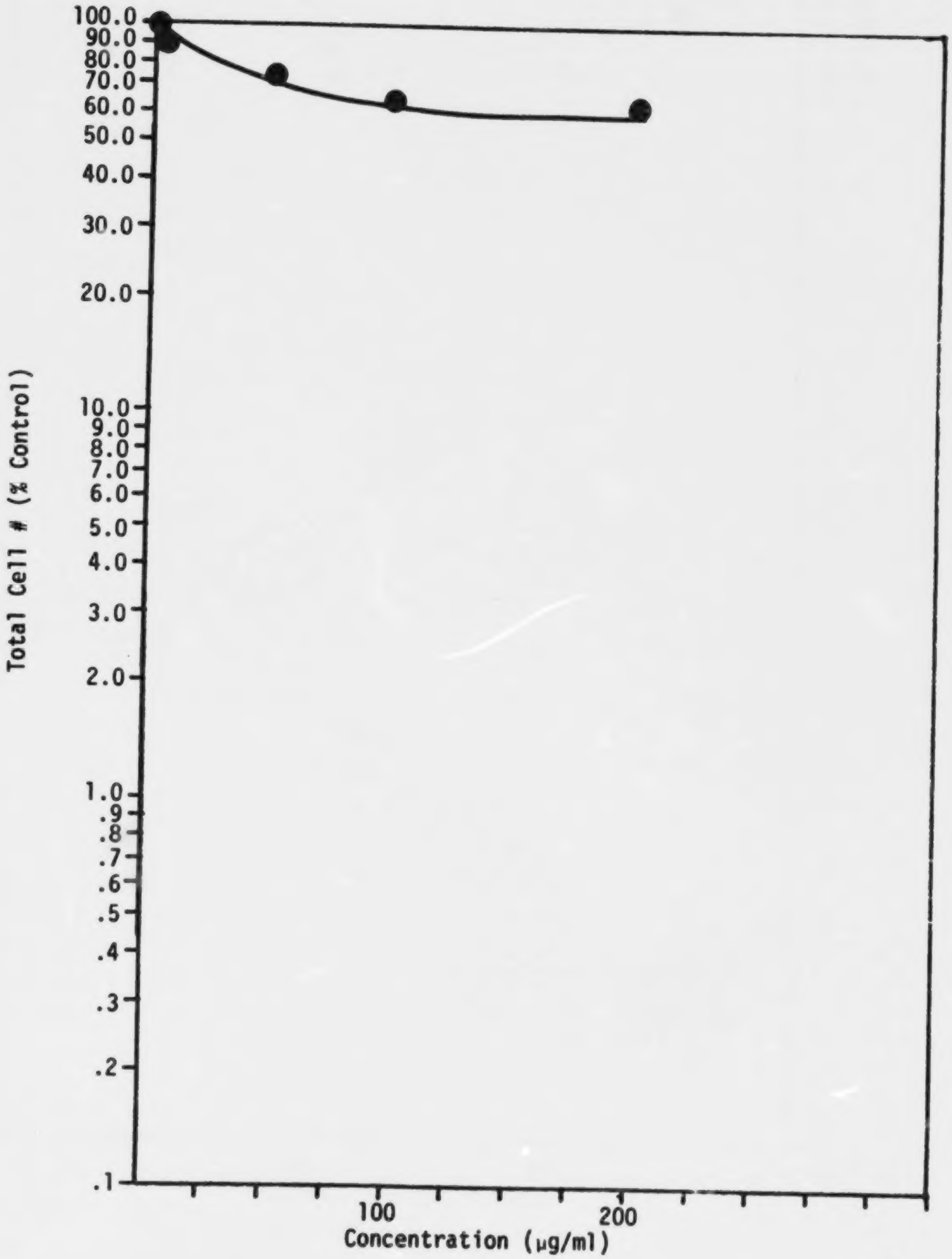
This is the same particulate matter, only it was extracted with the complete Dulbecco's, in other words, the tissue culture media with calf serum. You see a difference in the dose response relation ship.

Next slide, please. #16

This is total protein. With this type of system, this experiment, of course, is going to be repeated to fill in those gaps.

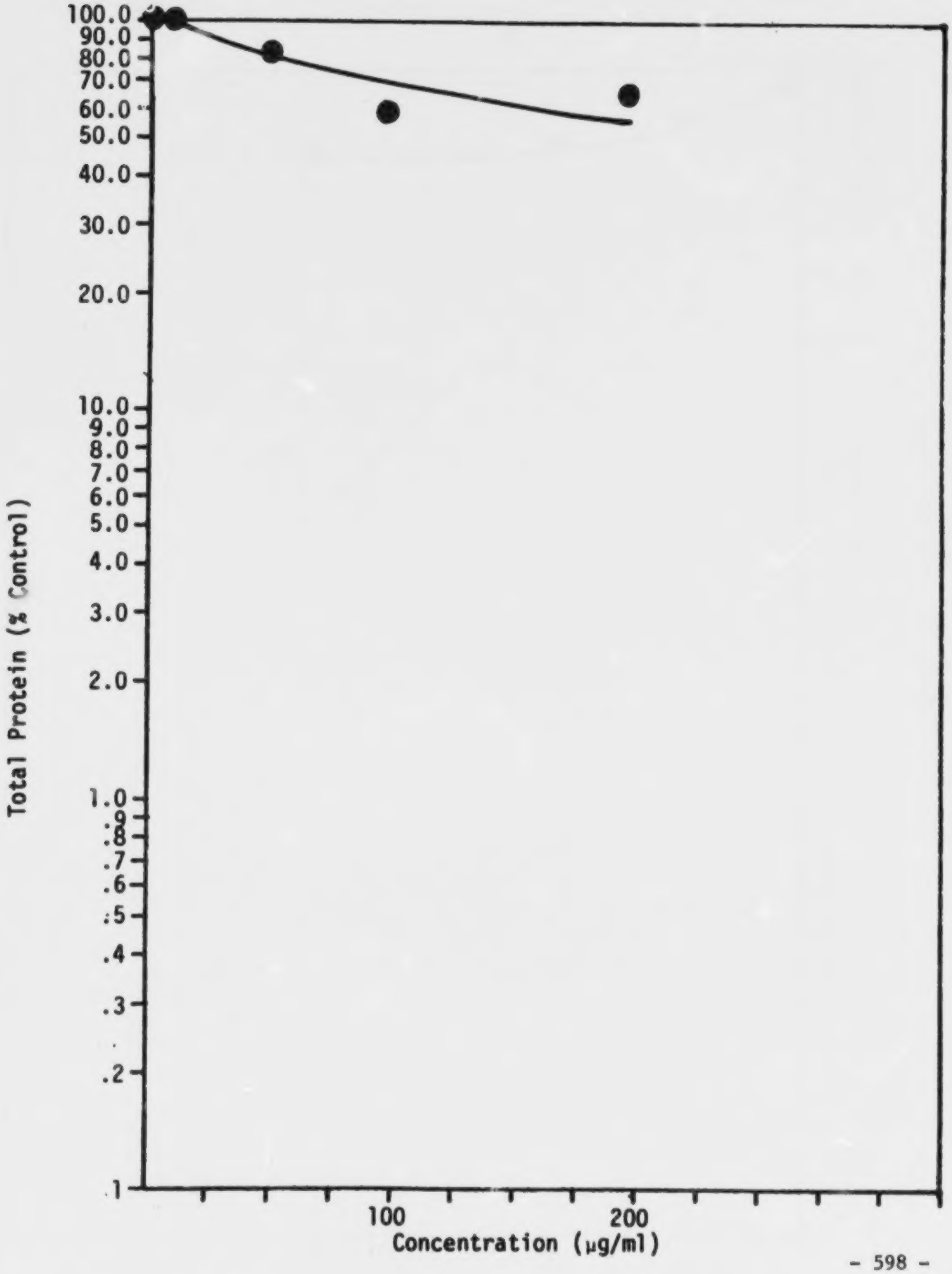
CYTOTOXICITY IN WI-38 HUMAN EMBRYONIC LUNG CELLS EXPOSED TO FLY ASH - WATER EXTRACT.

CROWLEY - 12



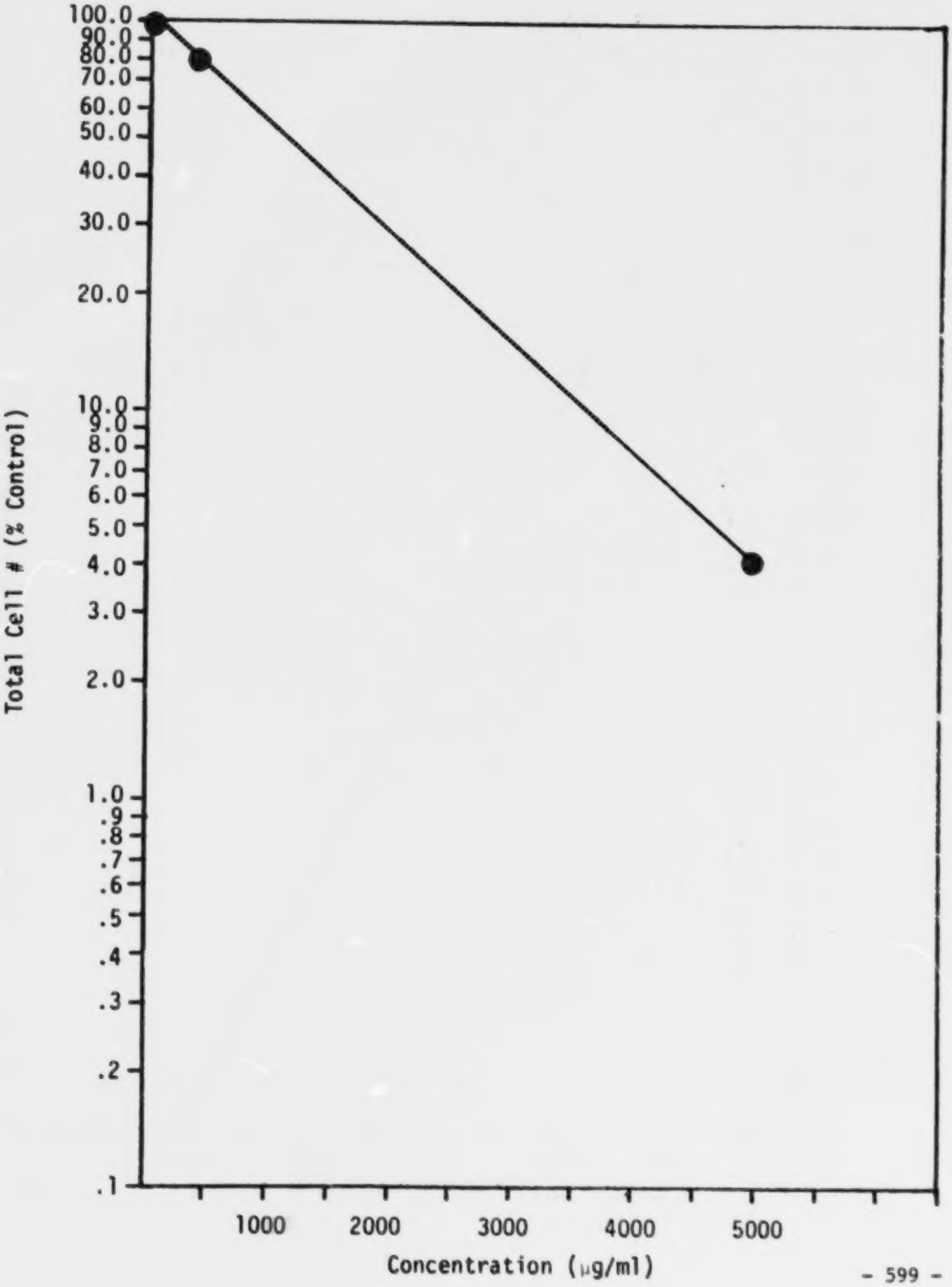
CYTOTOXICITY IN WI-38 HUMAN EMBRYONIC LUNG CELLS
EXPOSED TO FLY ASH - WATER EXTRACT

CROWLEY - 13



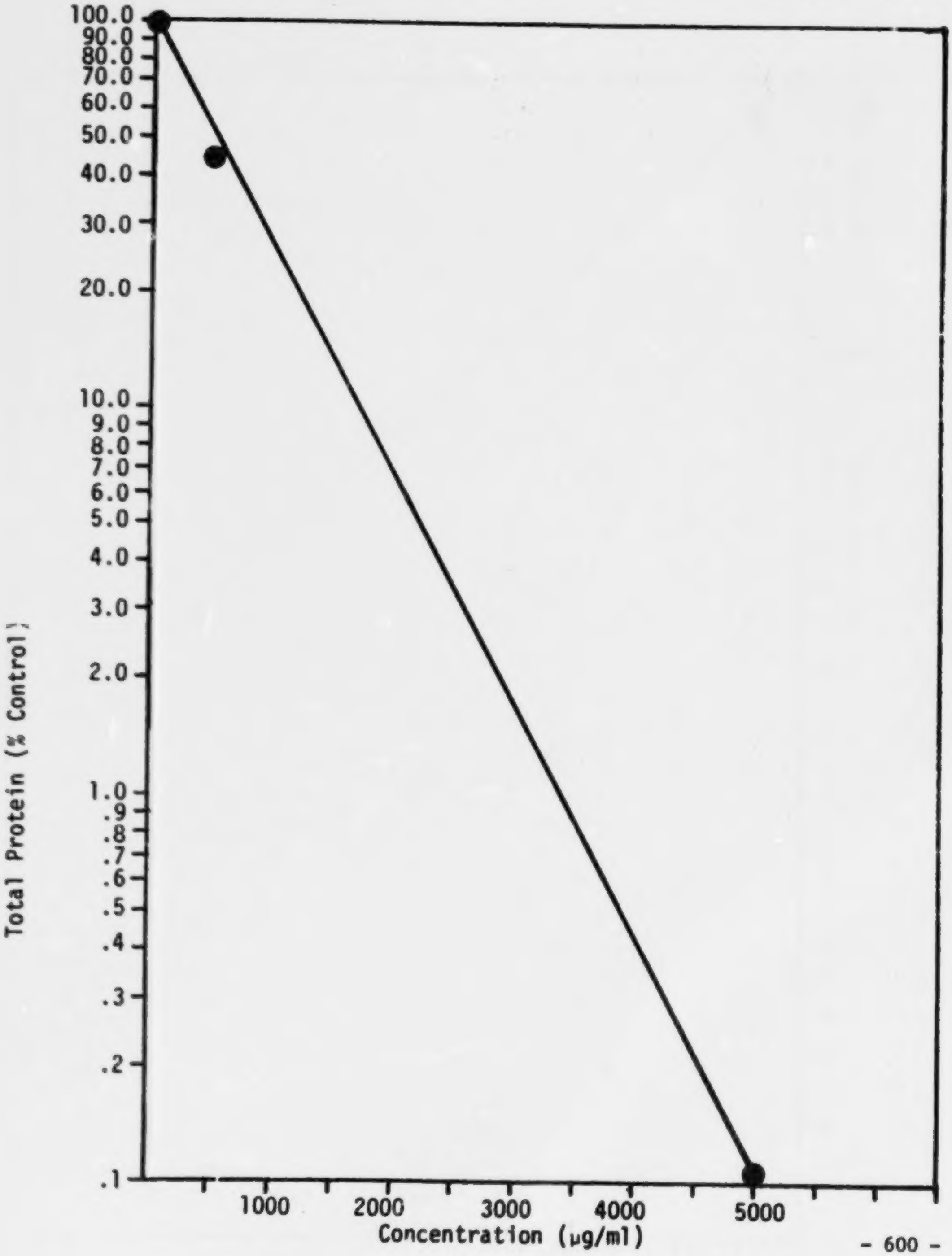
CYTOTOXICITY IN WI-38 HUMAN EMBRYONIC LUNG CELLS EXPOSED TO FLY ASH - DULBECCO'S (COMPLETE) EXTRACT

CROWLEY - 14

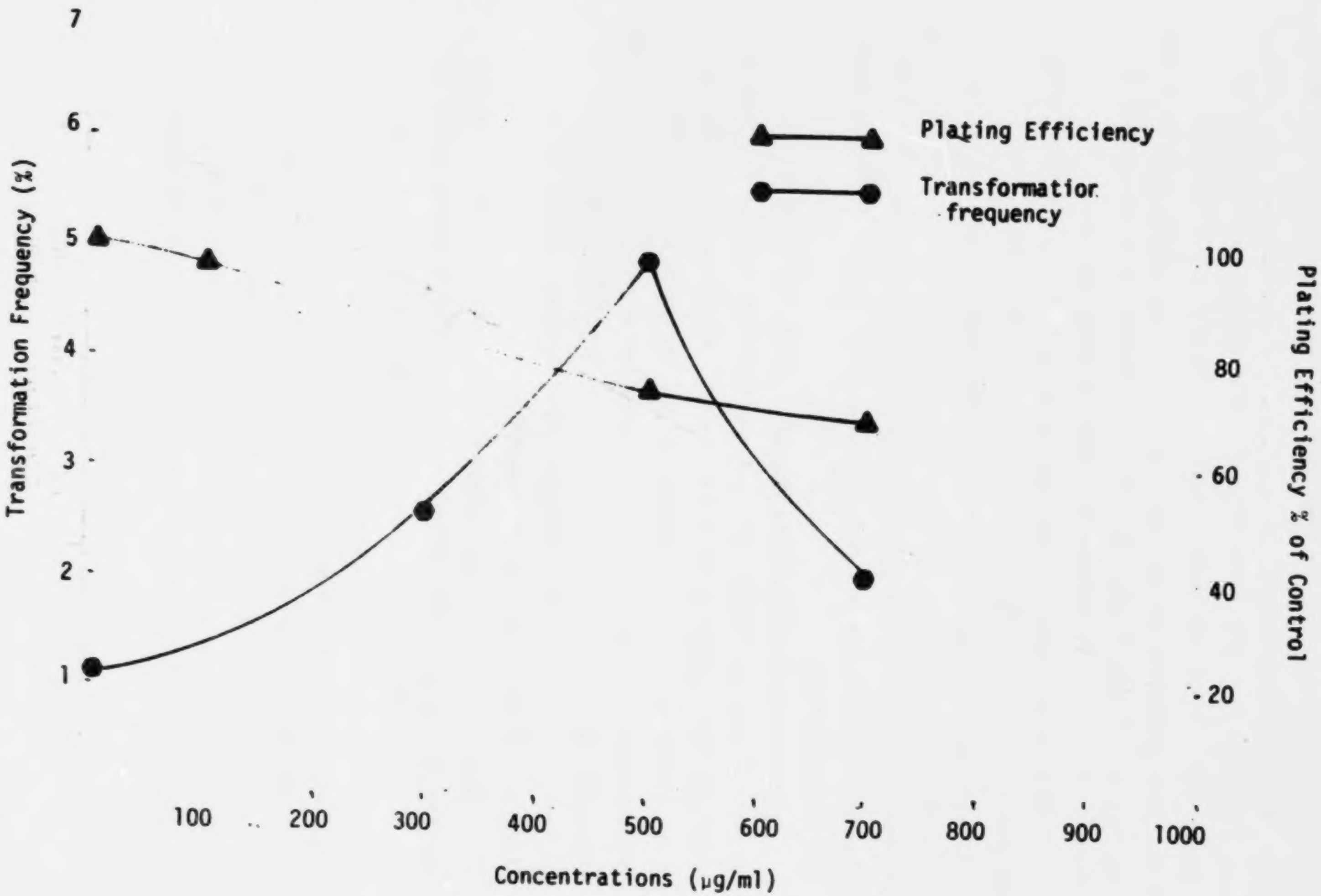


CYTOTOXICITY IN WI-38 HUMAN EMBRYONIC LUNG CELLS EXPOSED TO FLY ASH - DULBECCO'S (COMPLETE) EXTRACT.

CROWLEY - 15



C3H TRANSFORMATION FREQUENCY AND CYTOTOXICITY AS A FUNCTION OF EXPOSURE TO FLY ASH WATER EXTRACT.



But you can see in this particular sample in this system a difference between the total cell count and the total protein. Again, with this system, we also measure internal ATP concentration.

Next slide, please.

This is the last slide I have. This is lifted right out of a lab book. I did not have a chance to present it in the proper form for a presentation such as this. The first thing I would point out is that if any of you use this cell system, this should be .1 through 1.0, not 1.0 through 10. That is very important.

This is the same fly ash that I showed you in the first slide on the E. coli polymerase system that showed mutagenic effects preferential to serum type. We used this same extract, reran the E. Coli, reran the Ames, and put this into a C3H transformation assa assay cell system after the proper prescreen to delineate the dose response relationship so that the cells would not be disrupted from the plate surface.

Now, the C3H is probably the most sensitive in vitro cell system delineating morphological transformation today. I probably would get some arguments that the hamster embryo is a good system. It is a very good system; but one of the problems is that there are variables in the hamster embryo system that are hard to control, the source of embryos and things like this. The C3H system can be applied pretty universally between laboratories. It is now being validated by more and more laboratories.

This is a linear dose response. It is an arithmetic curve, and you can see the linear dose response. The triangle points are the cloning efficiency or cytotoxicity results from this one assay. Each point represents eight plates of the transformation. Each point of the triangle represents three plates.

The sharp fall off in transformation frequency, I have seen before. A compound actually can inhibit its own carcinogenic effect beyond certain concentrations. I am not saying that is what is happening here. I am just saying that that is a possibility.

This particular particulate is being reevaluated in this system and in the DNA repair system. At this point, in quarterly intervals for this particular contract, we sit down and go over the different samples, as many samples as are submitted. We go over these results, and then, based on that, we either can go into animal studies or pull out these transformed cells and do tumorigenic studies. We are now in the process. We have a program now where we are going to use these in particular in vitro systems and do comparative lung inhalation function studies. Again, like the EPA, we are starting those this summer also. We are looking forward to it because it should, we hope, really increase the knowledge in this gray area between in vitro and in vivo. Hopefully, we will get a better idea and expand the data base available to people as yourselves in the private sector to make judgments in early events.

Thank you very much.

DR. MILBY: Thank you very much, Dr. Crowley.

Our next speaker is Dr. Richard Pollak, who is a consultant for the Diesel Automobile Association.

DR. POLLAK: Thank you. Good afternoon.

There has been a pervasive problem at this workshop. It is a problem of defensiveness. That is because there has been an underlying assumption that the introduction of industrial technology always carries with it health hazards and severe health risks. This is a false contention. It is immediately subject to an empirical refutation. Just look around you, and you can see that to be true.

Now, an insidious argument has been brought forth by the environmentalist movement. That is, namely, since industry and technology must carry harmful effects and since we cannot see these effects, why then, cancer must be the hidden effect. So, it is said that cancer is the scourge of modern industrial society.

Well, at least this is a myth; more likely, it is a tool of insinuation and innuendo deployed against technological innovation and its industrial applications.

The incidence of cancer has not increased in the United States since 1900. Think about the period from 1900 on. The United States was characterized by a massive societal upheaval. The population shifted from the majority being located on the farm to being located in the city. Along with that shift, of course, was the shift to mechanization. The farms became highly mechanized, using among other things a lot of diesel tractors. The cities underwent a tremendous amount of growth, and, again, the infrastructure of the cities grew to depend greatly on diesels, buses, fire trucks, trucks in general, and so on. Of course, associated with this massive growth was the growth of the transportation system, namely, trucking carriers, which is almost an exclusively diesel industry.

Now, this is a tremendous social change. With this change, cancers should have increased dramatically if, as it is argued, industrial by-products are highly carcinogenic; so dramatically,that we would have seen a tremendous rise, a geometric rise, in cancer.

Now that just has not happened. When I say there has not been an increased incidence of cancer, let me clarify that from the statistics from the period 1990 on. Basically, if you account for the increase in the absolute numbers in your population and then account for the increase in the relative age groupings within that population, and then account for cigarette smoking, which is probably the single most well documented environmental insult to account for cancer, you see that there has been no increase in the incidence of cancer for the population as a whole.

Now, in their zeal that we have a risk free environment, and I do not know what that is exactly, but that is evidently the goal, the environmental scientists have mustered their imposing array of empirical tests, which, if you look at them very seriously, prove that we all should have died years ago. That is just not the case either.

First, there is the Ames test. That has been fairly well discredited here. Just to quickly go over why it has been discredited, it is among other the things the extrapolation from pseudo bacterialto a mammalian system. That extrapolation just bears no relation to reality at all.

Then you have this threshold problem. The threshold problem is really an interesting one, which I will discuss in a minute when we talk about mammalian testing. But it is interesting that if the study that Dr. Vostal was referring to does hold up, namely that the Ames test shows approximately a 50 percent correlation from bacteria to mammalian systems or to human cancers, it will have essentially invalidated the Ames test as an indicator of human health effects. Yet, the EPA is going to persist in using the Ames test as a screening method to decide what to test. They are actually better off going randomly down the line of their chemicals.

Now, let us look at animal studies. There are two main problems with animal studies. One, of course, again is this extrapolation to humans, which is the idea that animal systems and human systems are basically the same. Now, that is just obviously not true. The metabolic, biochemical, and anatomical differences really call for a great deal of caution in interpreting animal studies and extrapolating them to humans.

Just to give you one idea, penicillin, normally given subcutaneously with humans, when it is given subcutaneously in mice, it produces sarcomas. Under EPA guidelines, we could not use penicillin!

Now, the other thing is the question of thresholds. When you massively dose an organism, you oftentimes surpass the level at which those organisms have the capability of detoxifying the substance in question. Yet, if you take those results and then extrapolate down to lower levels, which is usually the methodology involved, you imply that even at low levels the effects are the same. Now, that is just not true. In fact, it implies a statistical model (this is discussed in great detail and in great insight by Dr. Cornfield in a Science publication last year).which has never been verified in biochemical studies or in metabolic studies. Technically, the ppoblem lies in the area of the directionality of biochemical processes. So, you are setting up a model which bears no relationship to reality when you extrapolate below a threshold level, which brings certain problems into your testing procedures. This is a troublesome area that actually must be addressed and addressed very carefully.

Of course, then you have the final question of the interpretation of the results. Hair dye is found to cause cancer in rats when the rats eat the hair dye. To extrapolate that to someone using hair dye on their hair and skin is a far fetched extrapolation. I would not advise people who use hair dye to drink it.

Then there was the Colorado researcher who inserted a coin into the peritoneum of a group of rats and found that these coins caused cancer. That says something about the money supply. It does not say anything about cancers as they relate to either the workplace or the environment as a general phenomenon.

The truth is that this "pure" environment just does not exist. Just even think of your drinking water. Calcium has been shown to b be carcinogenic by the FDA. If you took calcium out of your drinking water and drank doubly distilled water, which is found in every laboratory, you would very quickly be dead, because the doubly distilled water would leach out ions, including calcium, that are very essential to your metabolic being. Yet, the unpure water containing "carcinogens" is obviously in trouble.

The one set of data which appears to be the best data to use for evaluation purposes is epidemiological data. Again, this runs into some real problems, and I would like to discuss a few results that bear on both the problems and the strengths of this methodology.

There was a Swiss study by Blumer, et al, in 1977 on polyaromatic hydrobarbons in soils and the relationship to cancer in a Swiss village. The study found that there were two groups of individuals or families in this village. One lived by the road in older housing along a well traveled highway. The other lived further back off the highway in newer housing, in a place where there was very little traffic. It was the former that had higher incidences of cancer.

Now, this study has been implied by the environmentalists to show that diesels cause cancer. Yet, any careful reading of this study shows that it does not say that at all. In fact, it is actually quite a poor study. First of all, in looking at the study a little more carefully, diesels are never mentioned in the study itself; but then, let us look at some of the data collecting activity in the study. In terms of age groups, it never says how this town is divided. It is possible that, because there was a clear cut division in the age of the housing, perhaps you actually had a shift in your population, such that the younger people would be moving to this newer housing. I do not know; there was no data there. We will never know unless we go back and do this study again.

Were the water supplies the same? We do not know. Were the housing materials the same? Were the income levels the same? How about smoking habits, the occupational breakdown, and the material of the road? Not necessarily the vehicles that traveled on it, but what about the roadbed material itself? None of these parameters were investigated. How you can imply that diesels were the cause in the difference of incidence of cancers is beyond me, and it is beyond any rational individual.

Now, in contrast, there is an interesting study that is quoted by the Chairman's group, the Environmental Health Association, in a report for the American Mining Congress. It was based on their own data and the data of the 1972 National Academy of Science report. It talked about the exposure of benzo(a)pyrene to various sets of workers, and then correlating it to the exhaust of diesels.

Now, British gas workers were exposed in an eight-hour working day to 1,000 micrograms per 1,000 cubic meters of BaP. The increase in lung cancer in this group over the general population was the equivalent of individuals who smoked between one and 10 cigarettes a day; that is, half-a-pack-a-day smokers. This is approximately 1.5 times the national cancer rate.

Now, if you inhale undiluted straight tail pipe diesel exhaust, you would get 1/20th of that exposure to BaP. Of course, the correlative drop to the cancer rates is just slightly over normal.

For diesel exhaust in a ventilated mine, the BaP was actually below the normal ambient air in a city. The cancer rate for this exposure is below the normal cancer rate.

But, there is something more convincing in that report that was not mentioned in the discussion. It appears that there is actually a threshold phenomenon going on here. The BaP must actually get above very highly concentrated amounts before it actually has a significant environmental impact. If you look at the data carefully, you would see a linear projection of the rise in cancers correlated to the rise in BaP at a very low rate, up to well over 1,000 micrograms per 1,000 meters cubed.

However, for coke oven workers, another gorup of British workers, they had conditions where they were exposed to 10^5 micrograms per 1,000 meters cubed of BaP. The lung cancer incidence here increased up to the level of cigarette smokers who smoke between a half and one pack a day, which is approximately five times the urban rate of lung cancer. I would like to point out here that this is approximately 100,000 times the concentration of BaP that you would get from diesel exhaust in the confined space of a ventilated mine. Furthermore, as was pointed out here by others, the particulate size distribution of the exhaust lowers the lung retention of the BaP even further.

So, there you have an epidemiological study correlated to certain cancer inducing substances perhaps that indicates that in no way, at the levels that are being discussed here for diesel exhaust, is there anything beyond what we would normally call ambient air. Therefore, you would expect the same correlative results.

But we have to get back to the essential question here. That is the question of a no risk society. It is an illusion; That is the assumption that I want to finish this address with. The idea is that it is possible to separate out the biological risk to an individual as a result of the introduction of a particular form of technology from the contribution that that technology makes to the overall health of the society. The individual's biological health is not a category which is separable from societal growth and well being. There is no need for defensiveness on the part of manufacturers and people in the industrial technologies.

Let me just illustrate this concept briefly by looking at what happens when you introduce diesel equipment into a mine. Let us look at some of the risk factors in a mine in general. There is black lung disease. The risk there is 10,000 times 10^{-5}, or one out of every 10 workers. Coal accidents is another 1,500 times 10^{-5}. You are going in there knowing that you are going to get stricken down by a variety of possibilities. It is a very hazardous proffession, to say the least.

Yet, if you look at the data I presented just a moment ago, the increased risk of cancer is less than 1.5 over the normal from BaP from undiluted diesel exhaust. So, compare that to the risk of black lung disease and accidents. Think what diesel equipment does in a mine. It frees the number of workers needed. The introduction of machinery actually increases the labor power of the individuals in that mine, such that you need a concommitantly decreased number of workers in that mine in order to get out your same product. The cancer rate for the particular worker group actually declines for a given productivity.

So, let us say we get out a significant number of workers in that mine; what do they do? Well, first of all, as soon as you remove a significant number of workers by the introduction of this machinery, you have increased the health of those workers. That is obvious. No longer do they face black lung disease, coal accidents, and so on. You also increase society's health in a very significant way, because you now free these workers to go on and make diesel equipment, to administer other technological needs of society like inventing newer forms of technology which will eventually supercede the diesel and others. I do not mean to suggest that that is around the corner; but that has to come some day, and it will. The third thing is that this increased labor power can then also become biologists and medical personnel to deal with, and eventually cure, cancers.

You do not have to be defensive about this idea of introducing advanced technologies, even if they do perhaps increase the incidence of cancer on a very small basis, because the general health and well being of society, as well as for the individuals in the particular area, is obviously enhanced.

So, you could say that the introduction of this machinery brought a risk; but the overall effect of this is, obviously, positive. Indeed, this increase of free energy as a result of this introduction of technology may lead to other general health cures. I would like to point out that there was a report in last week's paper that for the first time in the history of mankind, for the last six months, there has not been a single case of smallp[illegible] reported anywhere on the globe. Now, this comes at the height of the expansion of the industrial technological basis of the globe's existence. It does not come as we retreat into a non-industrial society, whihh is what is ultimately demanded by the environmentalists.

Thus, the industrialization and the implementation of the accompanying technologies throughout this society has had an absolutely positive effect on the health and well being of the individuals. As I have pointed out earlier, the increase in cancer is simply due to the increase in lifespan and the age grouping. That increase in lifespan was a direct result of the most massive industrialization in the history of the globe, from 1900 to 1975 in the United States.

The opposite to this idea, the Malthusian viewpoint or the environmentalist viewpoint, has to be taken on on the grounds that I have just laid out here, the grounds that an increased societal health is the basis of an increased individual's biological health. All other arguments and all other discussions here, swappin ping technical data, and so on, can only be seen in that context. Once we get out the basic conception of the necessity of the increased global expansion of the mechanization and industrialization and accompanying technologies of society, then these technological arguments and discussions have the relevant meaning for further implementing technological innovations.

Thank you.

DR. MILBY: Thank you, Dr. Pollak, for a very interesting presentation. We will move right along, if we may, and ask Dr. William Thilly from MIT to address us next.

Dr. Thilly is from the Genetic Toxicology Laboratory at MIT.

(Written paper follows.)

GENETIC TOXICOLOGY OF KEROSENE SOOT

Debra A. Kaden

William G. Thilly

Toxicology Group

Department of Nutrition and Food Science

Massachusetts Institute of Technology

Room E18-666

Cambridge, Massachusetts USA 02139

As Presented

At The Workshop on Unregulated Diesel Emissions

And Their Potential Health Effects

Washington, D.C.

April 27-28, 1978

ABSTRACT

The mutagenicity of the polycyclic-aromatic-hydrocarbon-containing fraction of several soot samples was measured in *Salmonella typhimurium* using 8-azaguanine resistance as a genetic marker. In order to allow metabolism of pro-mutagens to their biologically active forms, a post-mitochondrial supernatant drug-metabolizing system derived from livers of phenobarbital- and/or aroclor-pretreated rats was incorporated into all assays.

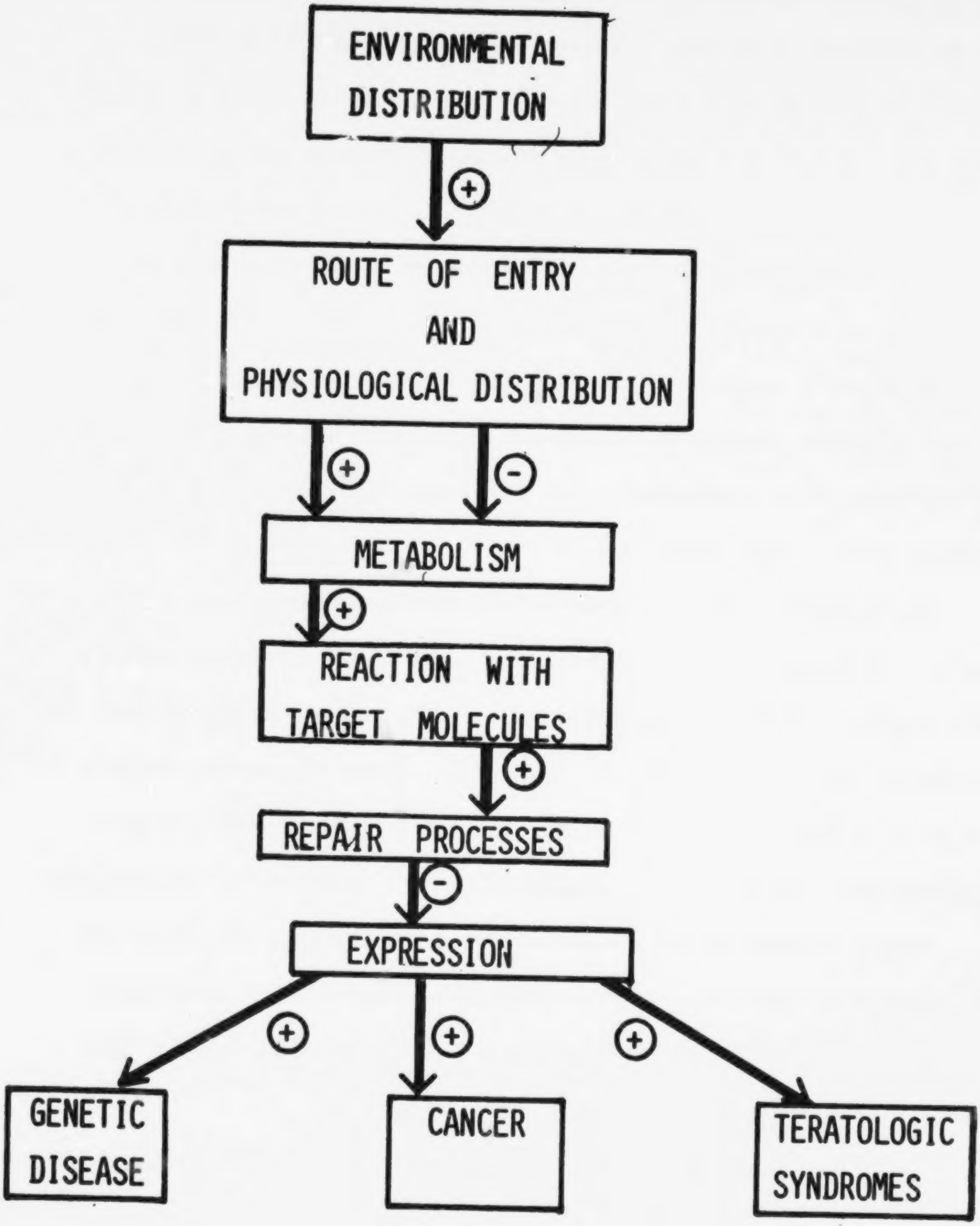
The mutagenicity of the soot extracts was ten to twenty times higher than could be solely accounted for by the amount of benzo(α)pyrene present in each sample.

The major polycyclic aromatic hydrocarbon components of a representative soot were quantitatively assayed for mutagenic activity to *S. typhimurium*. The possible explanation of synergism occurring between benzo(α)pyrene and other components of the soot extracts was discounted due to the additive mutagenicity of soot extract and added benzo(α)pyrene. Two of these components, perylene and acepyrylene, were found to be more mutagenic to *S. typhimurium* than benzo(α)pyrene. It now appears that all of the mutagenic activity of the fresh soot extract can be accounted for by the additive contribution of its various polycyclic aromatic hydrocarbon components.

In studying the interactions of chemicals in man we must consider the route of exposure and the internal physiological distribution of the substance in question (Figure 1). For instance, that which is respired, held in the lung, and then coughed up and swallowed is not simply an exposure of the lung, but is also an exposure of the broader gastro-intestinal tract, the hepatic circulation, and anywhere else that a compound which has entered the hepatic circulation can reach. We must consider the necessity for many compounds of metabolic activation before they can react with nucleic acid, the genetic material. We must consider the problems of reaction with target molecules. Many speakers today have referred to the huge differences between the arrangement of genetic material in the bacteria *Salmonella typhimurium* and in human cells. These materials are physically and chemically distinct in their character. DNA repair processes are quite species-specific. In fact, it is important to realize that there are even marked qualitative differences between the DNA repair systems of rodent cells and human cells. Finally, we must consider the problems of expression of mutant phenotypes *in vivo*, an area where very little is understood.

I would like to present to you some experiments relevant to one aspect of these broader questions. These experiments have been performed using a bacterial mutation assay developed in our laboratory, which we suggest should be seriously considered by those who are using *S. typhimurium* as a prescreen or fast screen method. This system is very

THILLY - 1


ENVIRONMENTAL DISTRIBUTION
+
ROUTE OF ENTRY AND PHYSIOLOGICAL DISTRIBUTION
+
-
METABOLISM
+
REACTION WITH TARGET MOLECULES
+
REPAIR PROCESSES
-
EXPRESSION
+
+
+
GENETIC DISEASE
CANCER
TERATOLOGIC SYNDROMES

simple to utilize; Figure 2 sums up the procedure. Essentially, exponentially growing bacteria are exposed to a test agent in the presence of a drug-metabolizing system. Cultures are then poured out onto plates which provide selective or non-selective conditions. By counting colonies that arise on both sets of plates and dividing bacteria on selective plates by those on non-selective plates, it may be determined what fraction of the bacterial population has been mutated to resistance to the selective condition; in this case, 50 μg/ml 8-azaguanine. This assay is equisensitive to the most sensitive of Ames' assays for all compounds which we have examined. Instead of dealing with what seems to be an obvious requirement for five different tested strains in reversion assays, one simply uses a single assay with one strain of S. typhimurium.

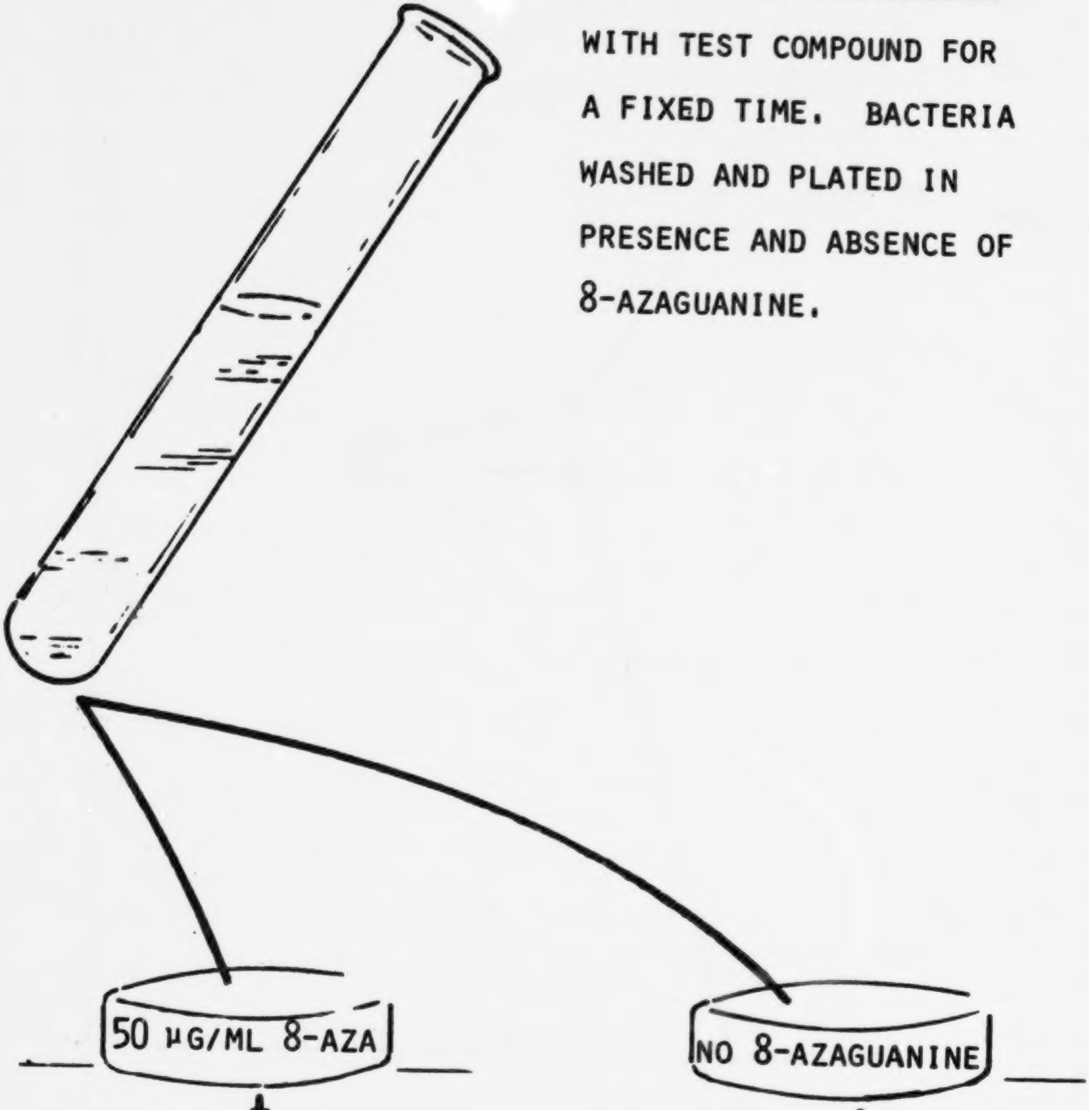
An important point not recognized by many people is that one has to determine the toxicity which has occurred as a result of the exposure to a test agent. This is necessary when trying to accurately determine the mutagenicity of a compound. If a test agent is toxic as well as mutagenic to the bacterial culture, it is possible to kill all of the mutants you have induced and come to the false conclusion that the test agent is non-mutagenic.

Figure 3 demonstrates a case where, had toxicity not been taken into account, a serious error in determining the mutagenicity of a test agent may have been made. The compound, 5,6-benzoquinoline, is very mutagenic, but it is also very toxic to S. typhimurium.

Using this bacterial mutation assay, we have examined the methylene

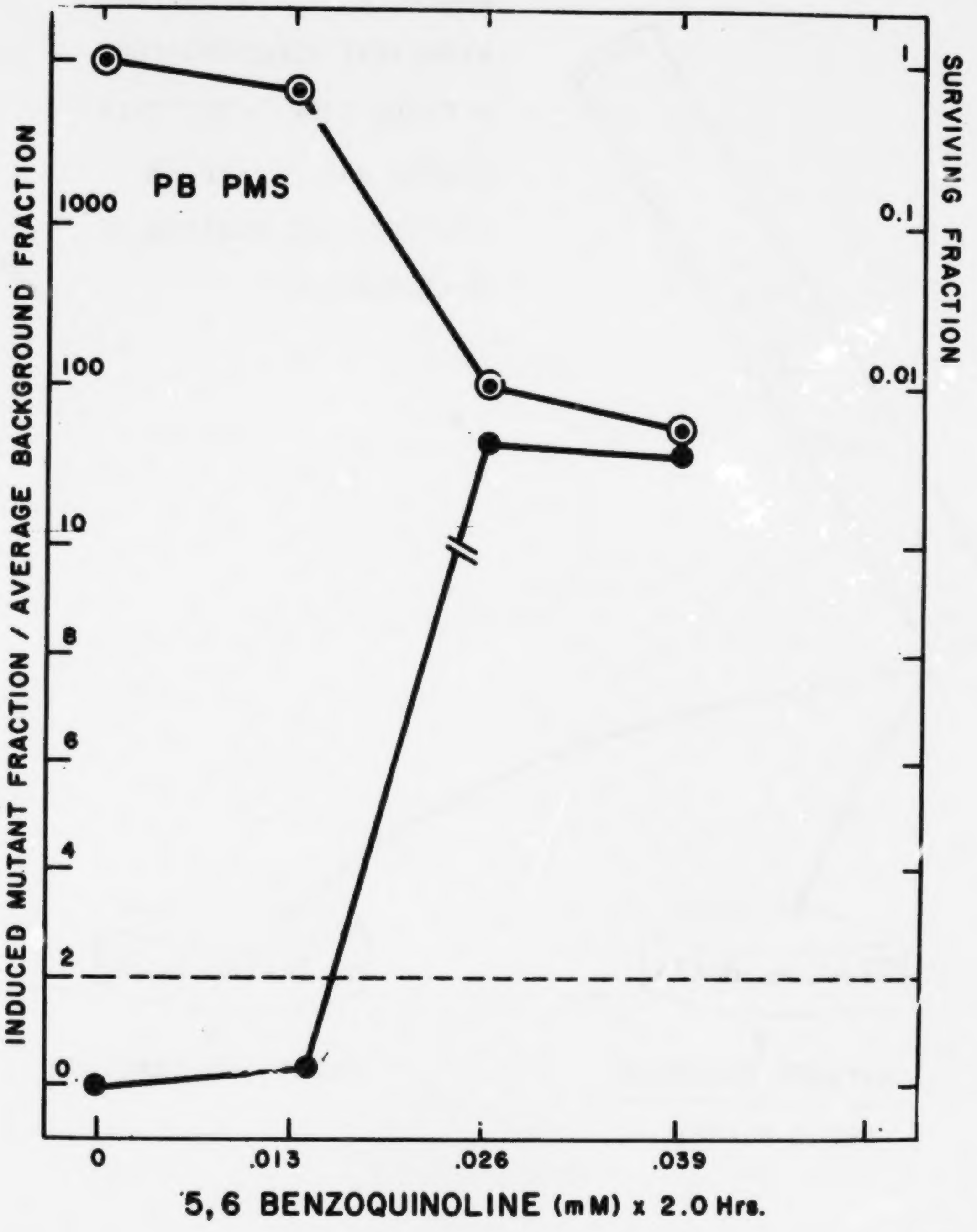
QUANTITATIVE FORWARD MUTATION ASSAY

BACTERIA IN SUSPENSION WITH TEST COMPOUND FOR A FIXED TIME. BACTERIA WASHED AND PLATED IN PRESENCE AND ABSENCE OF 8-AZAGUANINE.



MUTANTS OBSERVED
CELLS PLATED

SURVIVING FRACTION


PB PMS
INDUCED MUTANT FRACTION / AVERAGE BACKGROUND FRACTION
1000
100
10
8
6
4
2
0
SURVIVING FRACTION
1
0.1
0.01
0
.013
.026
.039
5,6 BENZOQUINOLINE (mM) x 2.0 Hrs.

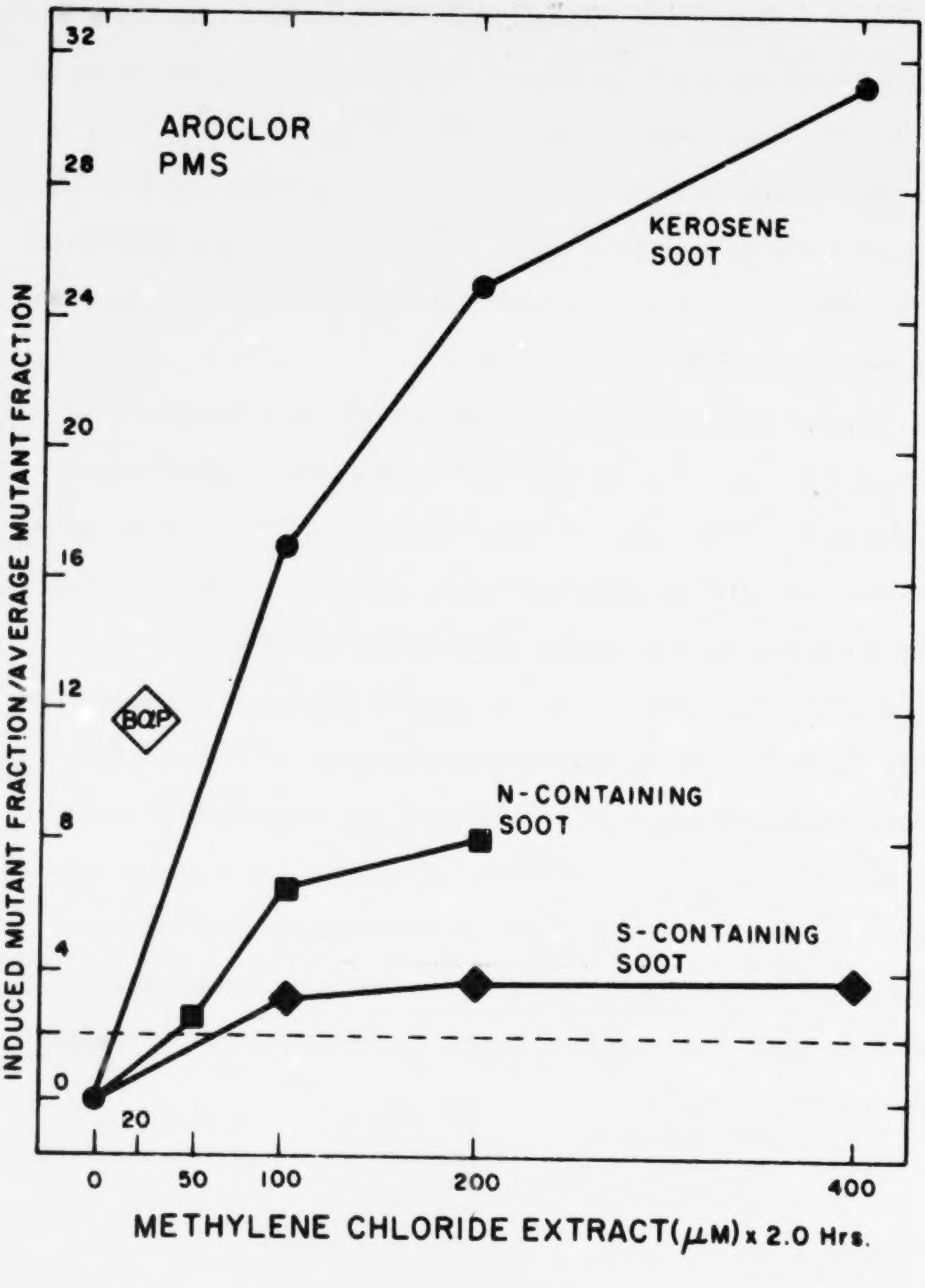
chloride extracts of soots from several sources (Figure 4). The kerosene soot is produced in a turbulent flame combustor at 1800 K and collected on a water-cooled probe. High-nitrogen and high-sulfur soots are produced through burning of pyridine- or thiophene-containing fuel mixtures. Carbon black was obtained from a commercial source.

As is evident in Figure 4, these extracts exhibit about ten to twenty-five percent of the mutagenic activity of benzo(α)pyrene on a weight basis. This result was surprising, because benzo(α)pyrene represents less than one percent by weight of this fraction.

Figure 5 summarizes the composition of the methylene chloride extract of kerosene soot, as determined by gas chromatography/mass spectrometry. Over eighty percent of the total polycyclic fraction of the kerosene soot has been identified by these methods, with the only component having any known mutagenic activity being benzo(α)pyrene.

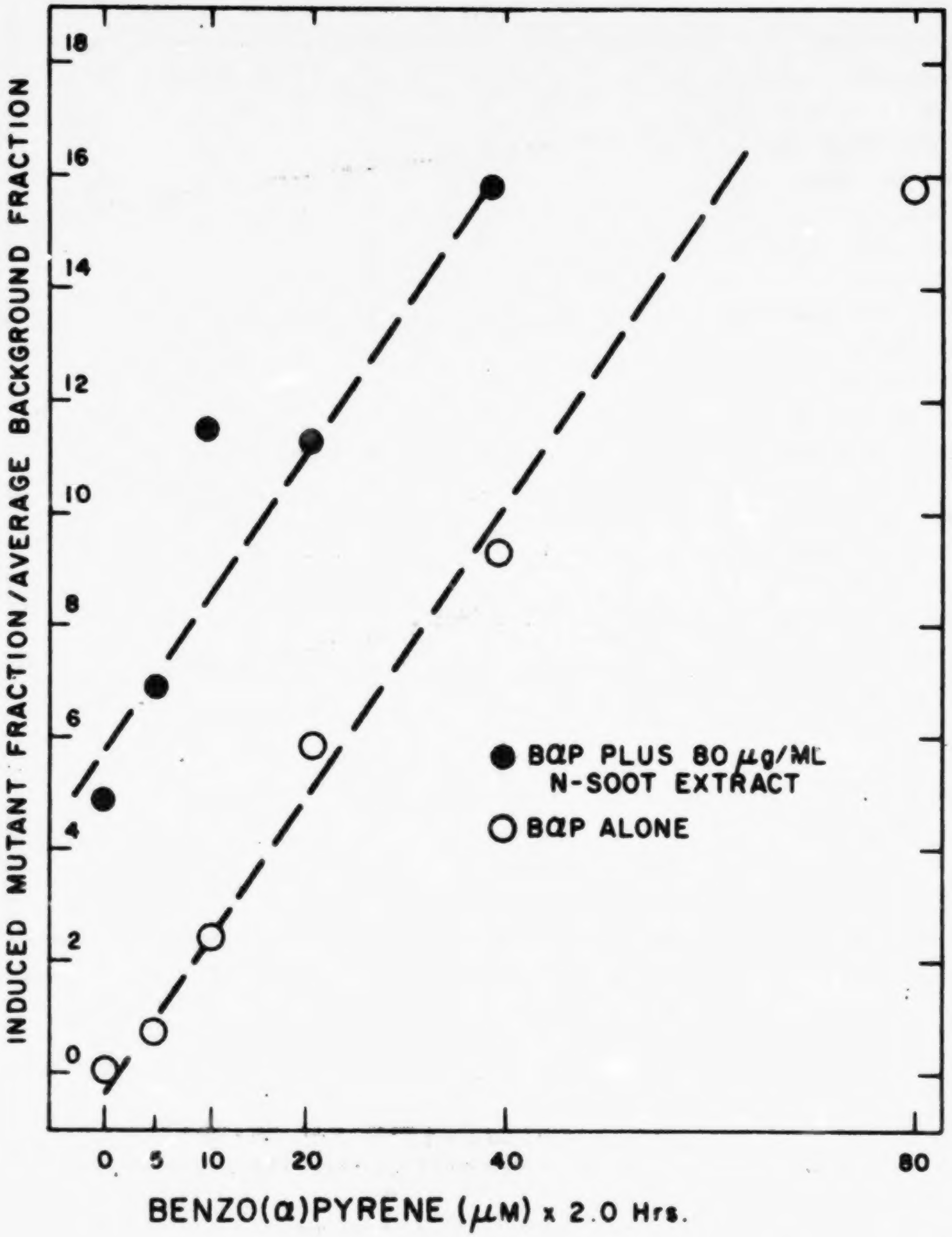
One possible explanation for this was that there were synergistic effects between benzo(α)pyrene and non-mutagenic components. Figure 6 demonstrates a simple experiment in which the mutagenicity of benzo(α)pyrene was measured in the presence and absence of a mutagenic amount of a raw soot extract. Results show a strictly additive relationship between the mutagenicity of benzo(α)pyrene and that of soot, indicating that synergism of the magnitude required to explain soot's high mutagenicity is not occurring.

An alternative hypothesis for the soot extracts' high mutagenicity is


AROCLOR
PMS
KEROSENE SOOT
N-CONTAINING SOOT
S-CONTAINING SOOT
BaP
INDUCED MUTANT FRACTION/AVERAGE MUTANT FRACTION
0
4
8
12
16
20
24
28
32
20
0
50
100
200
400
METHYLENE CHLORIDE EXTRACT(μM) x 2.0 Hrs.

GENETIC ACTIVITY ACCOUNTING
KEROSENE SOOT $MeCl_2$ EXTRACT

COMPOUND	RELATIVE MUTAGENIC ACTIVITY	WEIGHT(%)	EXPECTED RELATIVE WEIGHTED ACTIVITY
ACENAPHTHYLENE		23	
ACEPYRYLENE		15	
PYRENE		8	
BENZO(GHI)PERYLENE + ANTHANTHRENE		8	
CORONENE		5	
FLUOANTHENE		4	
NAPHTHALENE		3	
BENZO(GHI)FLUOANTHENE		3	
PHENANTHRENE + ANTHRACENE		2	
BENZACENAPHTHENE		2	
BENZOFLUORANTHENE		2	
PERYLENE		2	
ACENAPHTHENE		1	
INDENO(1,2,3-CD)PYRENE		1	
BENZO(α)PYRENE + BENZO(E)PYRENE		1	
4H-CYCLOPENTA(DEF)-PHENANTHRENE		1	
BENZOFLUORENE		0.4	
FLUORENE		0.3	
UNCHARACTERIZED MATERIAL		18.3	
Σ COMPONENTS			
$MeCl_2$ EXTRACT	0.20	100.0	0.20


INDUCED MUTANT FRACTION/AVERAGE BACKGROUND FRACTION
0
2
4
6
8
10
12
14
16
18
0
5
10
20
40
80
BENZO(α)PYRENE (μM) x 2.0 Hrs.
● BαP PLUS 80 μg/ML N-SOOT EXTRACT
○ BαP ALONE

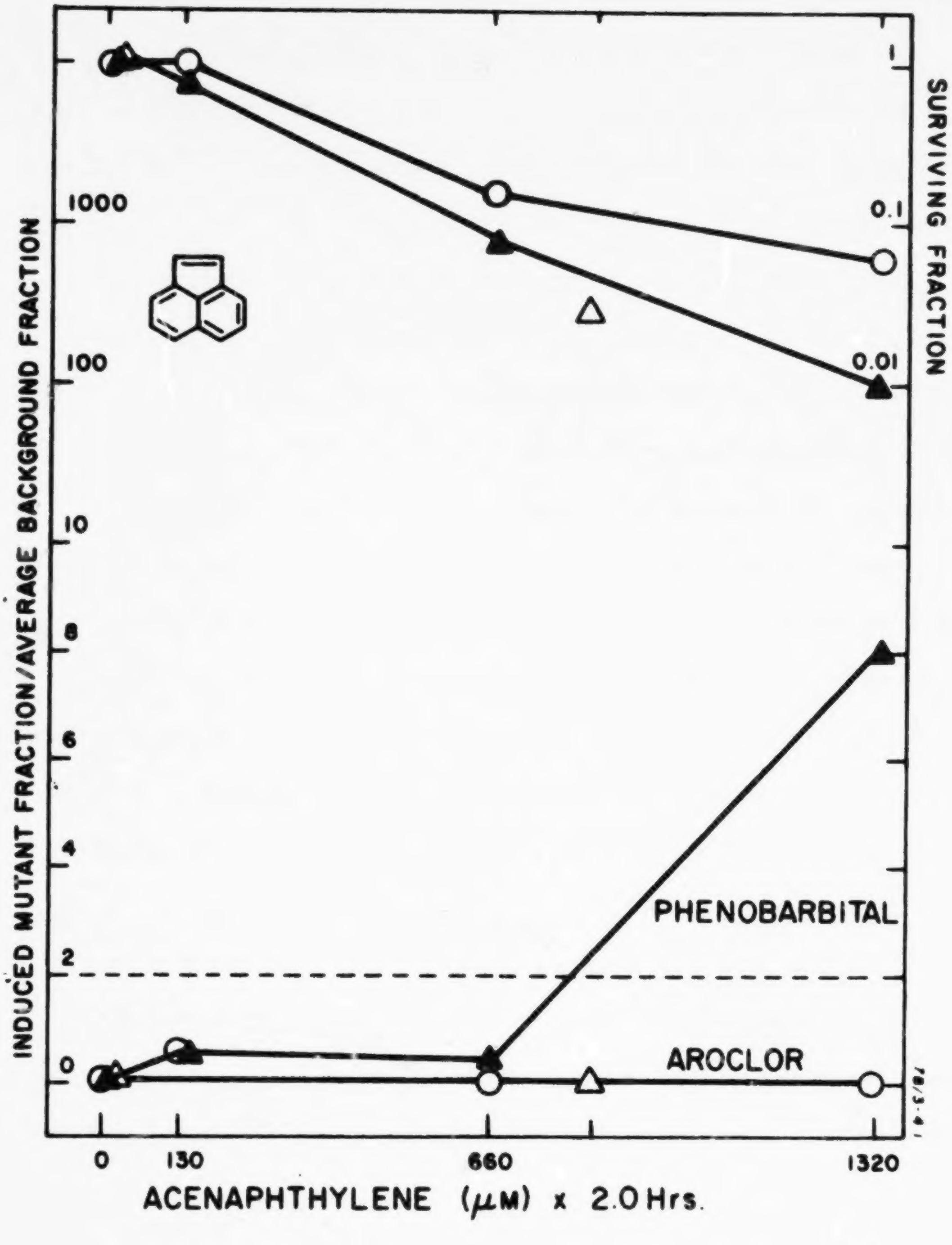
that some of these other polycyclics are contributing to the activity of the soot. Although the literature reports little or no activity of these compounds, we set out to evaluate them in our bacterial mutation assay.

As shown in Figure 7, acenaphthylene exhibits mutagenic activity in the presence of a phenobarbital-induced drug-metabolizing system. This activity is not enough to begin to explain soots' high mutagenicity. The same case holds for pyrene (Figure 8).

Acepyrylene, however, appears to be on the order of one to two times as active as benzo(α)pyrene on a molar level, and because it contributes to 15% by weight of the polycyclic fraction, it alone can account for all of the soot extract's activity (Figure 7). We have extended our studies on the mutagenicity of acepyrylene and of soot to human cells, and have seen that acepyrylene is only fifty percent as active as benzo(α)-pyrene, while the soot extracts exhibit approximately thirty percent of the activity of benzo(α)pyrene. This kind of a variation among species, while significantly different in a quantitative sense, is probably not important in an overall biological sense to the use of this bioassay.

Figures 10 and 11 illustrate the relative inactivity of benzoperylene and phenanthrene.

Perylene, as shown in Figure 12, appears to be an extremely active compound. Interestingly enough, it is widely distributed throughout the environment. Approximately two percent of the fresh kerosene soot polycyclic fraction is made up of perylene. It can be found in great quantities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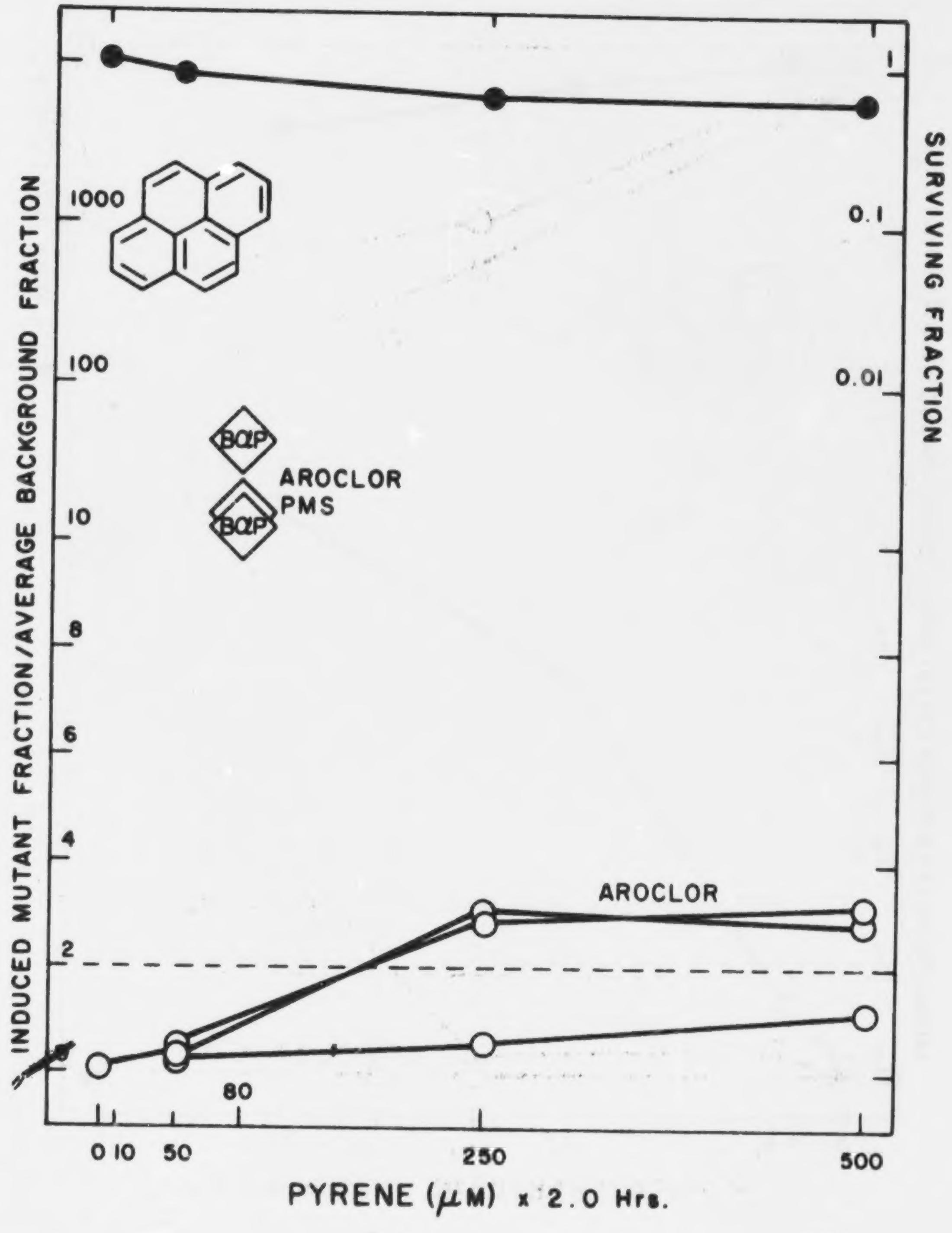
SURVIVING FRACTION
1000
100
10
8
6
4
2
0
1
0.1
0.01
PHENOBARBITAL
AROCLOR
0
130
660
1320
ACENAPHTHYLENE (μM) x 2.0 Hrs.
78/3-4-1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SURVIVING FRACTION
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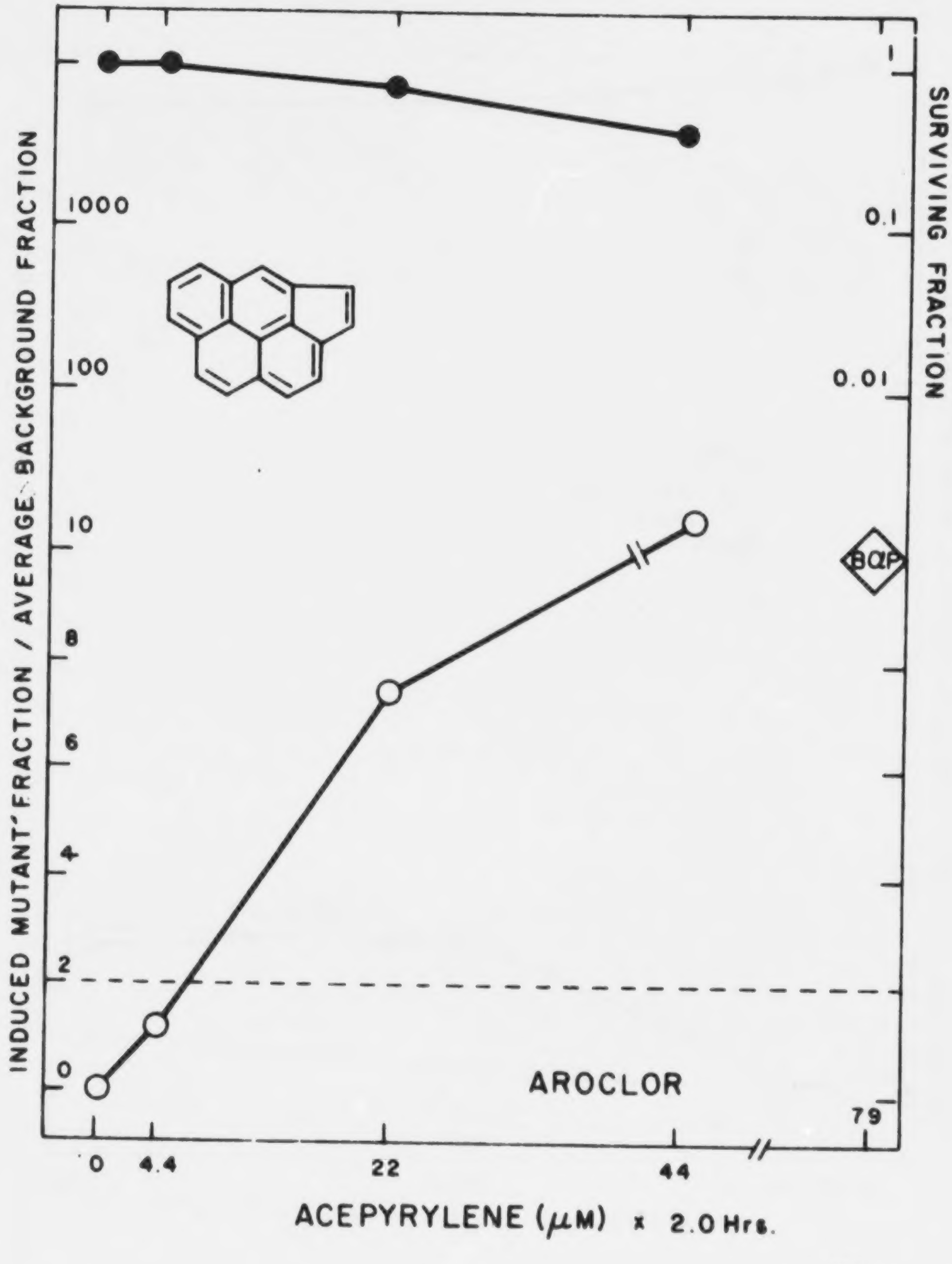
1
0.1
0.01
BαP
AROCLOR
PMS
BαP
AROCLOR
80
0 10
50
250
500
PYRENE (μM) x 2.0 Hrs.


INDUCED MUTANT FRACTION / AVERAGE BACKGROUND FRACTION
1000
100
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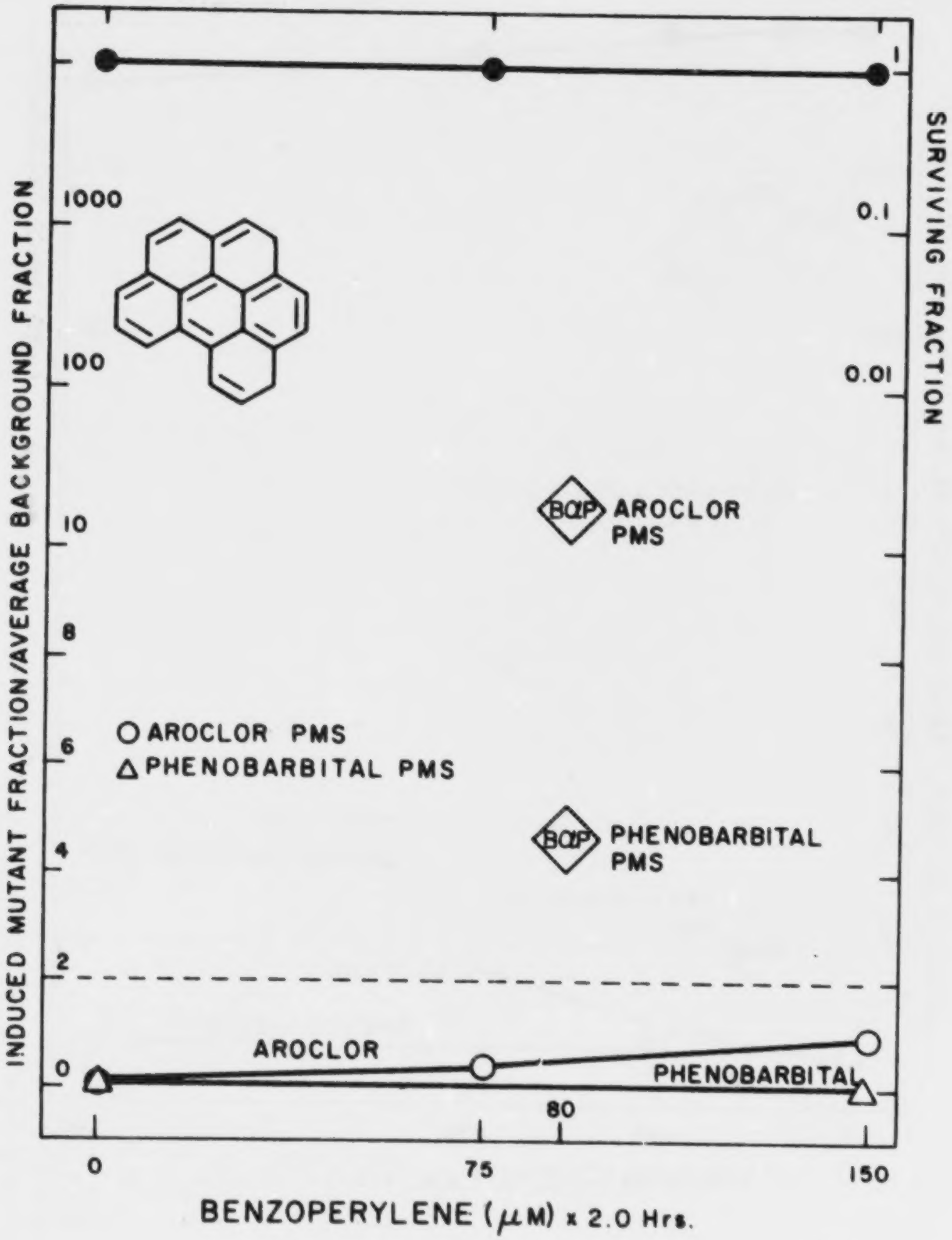
8
6
4
2
0
SURVIVING FRACTION
1
0.1
0.01
BαP
AROCLOR
79
0
4.4
22
44
ACEPYRYLENE (μM) x 2.0 Hrs.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1000
100
10
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6
4
2
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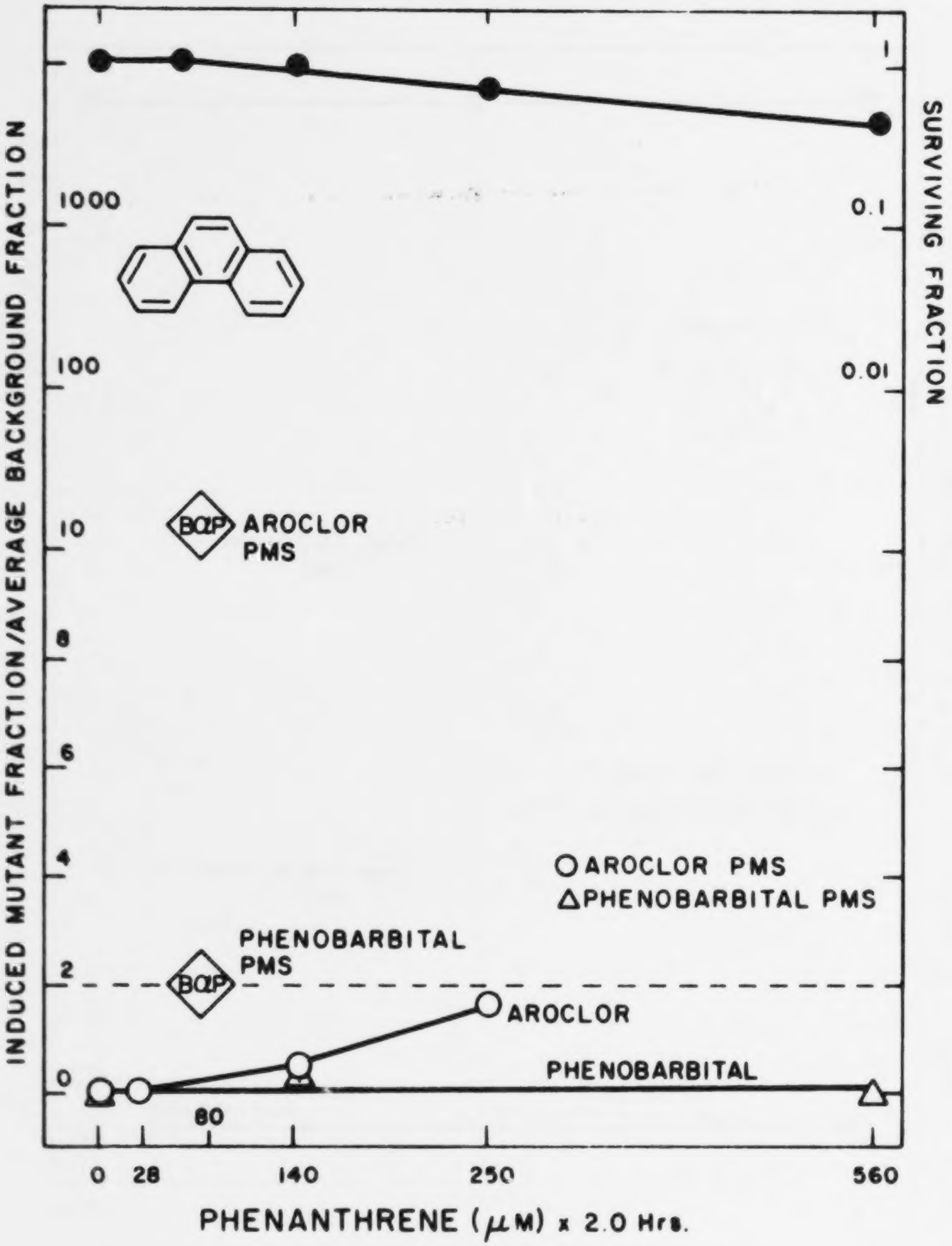
SURVIVING FRACTION
1
0.1
0.01
BαP AROCLOR PMS
BαP PHENOBARBITAL PMS
○ AROCLOR PMS
△ PHENOBARBITAL PMS
AROCLOR
PHENOBARBITAL
80
0
75
150
BENZOPERYLENE (μM) x 2.0 Hrs.


INDUCED MUTANT FRACTION/AVERAGE BACKGROUND FRACTION
SURVIVING FRACTION
1000
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8
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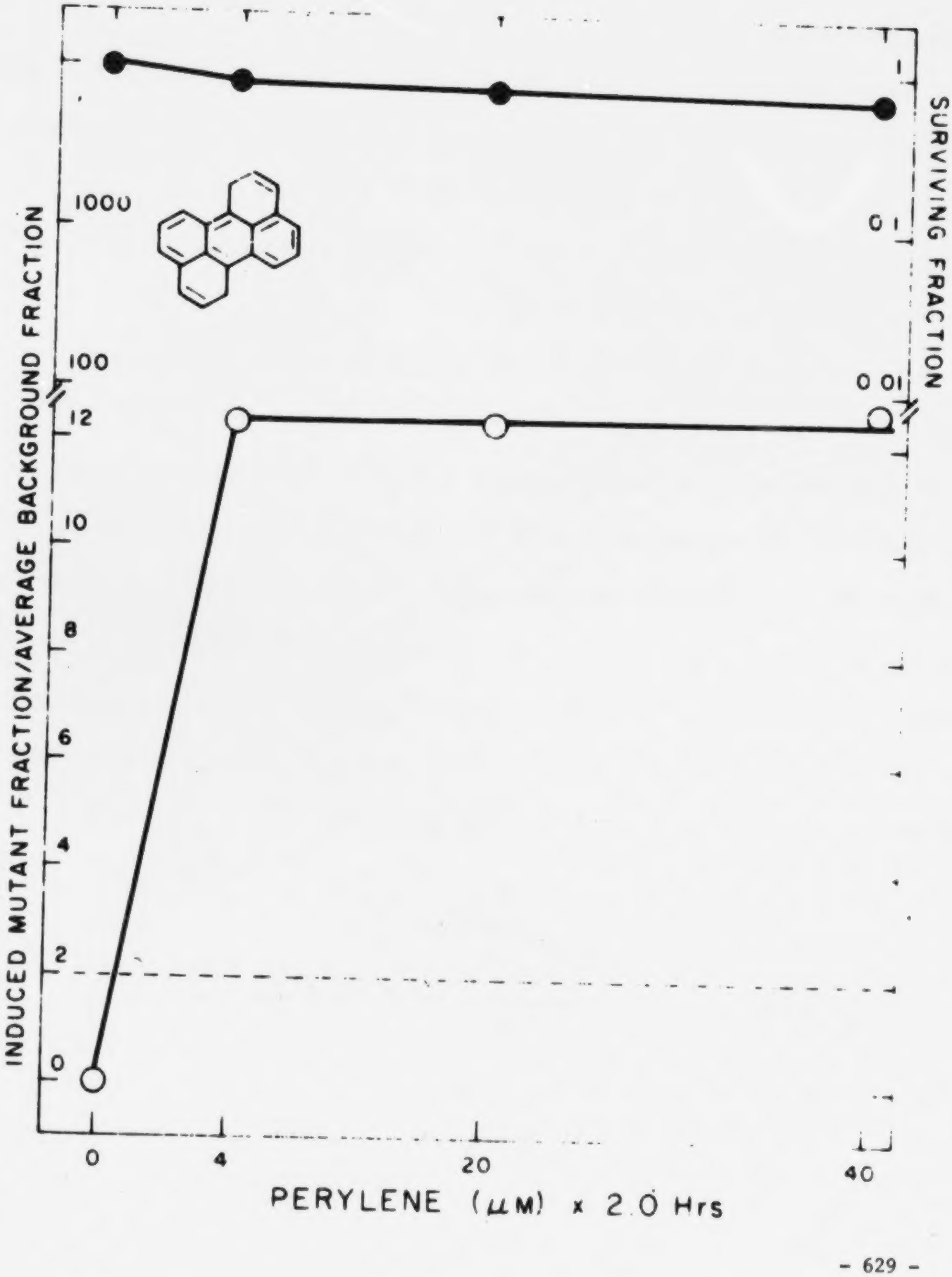
0.1
0.01
BαP AROCLOR PMS
BαP PHENOBARBITAL PMS
○ AROCLOR PMS
△ PHENOBARBITAL PMS
AROCLOR
PHENOBARBITAL
80
0
28
140
250
560
PHENANTHRENE (μM) x 2.0 Hrs.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SURVIVING FRACTION
1000
100
12
10
8
6
4
2
0
0.1
0.01
0
4
20
40
PERYLENE (μM) x 2.0 Hrs

in sludge and sediments of various estuaries and rivers. Perylene was found to be negative when painted on mouse skin, but it appears to be responsible for the finding that 40% of certain populations of salamanders had skin tumors.

In our bacterial assay, perylene is about six times as active as benzo(α)-pyrene, and an account for approximately half of the soot extracts' mutagenicity. It should be noted that there are no fewer than two bay regions in perylene, which might be oxidized in a manner similar to dibenzanthracene, chrysene, or benzo(α)pyrene.

Figure 13 shows the mutagenicity of benzo(α)pyrene, a compound used as a control and method of comparison throughout our studies.

In summary, all of this data shows a remarkably simple conclusion (Figure 14). By simply multiplying the mole fraction times the activity relative to benzo(α)pyrene and adding these fractions, we can account for all the activity of a soot extract. No synergism need be invoked. If anything, what we are probably now seeing is a partial competitive inhibition of the oxygenation reaction in the rat-liver post-mitochondrial supernatant. Experiments to examine this are now in progress.

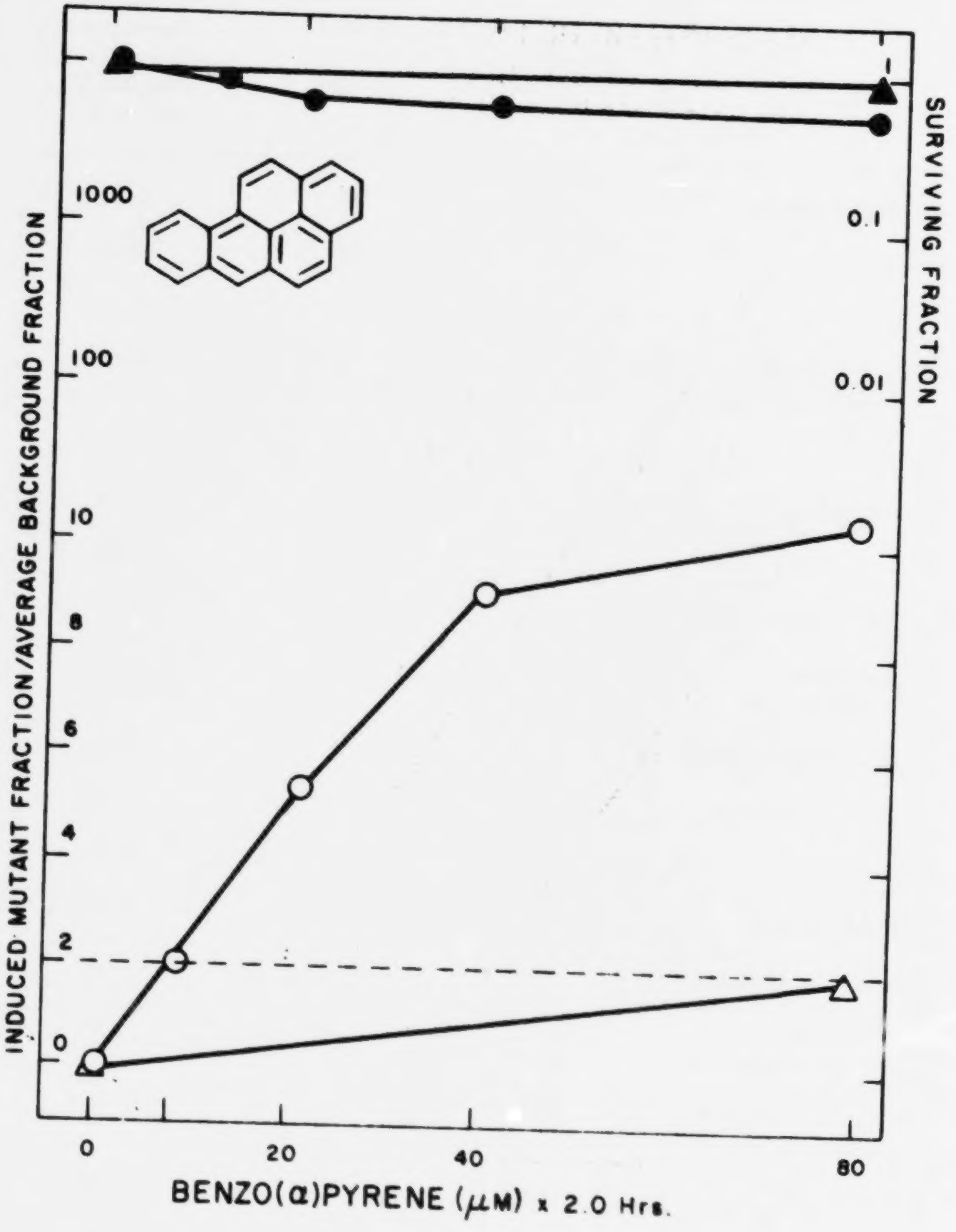

INDUCED MUTANT FRACTION/AVERAGE BACKGROUND FRACTION
1000
100
10
8
6
4
2
0
SURVIVING FRACTION
1
0.1
0.01
0
20
40
80
BENZO(α)PYRENE (μM) x 2.0 Hrs.

FIGURE 14

Mutagenic Activity Accounting of Kerosene Soot $MeCl_2$ Extract

Compound	Relative Mutagenic Activity	Weight	Expected Relative Weighted Activity
Acenaphthylene	0.07	23	0.02
Acepyrylene	1.5	15	0.23
Pyrene	0.07	8	0.01
Benzo(ghi)perylene + Anthanthrene	< 0.01 0.09	8	0.00
Coronene	----	5	----
Fluoranthene	----	4	----
Naphthalene	<0.01	3	0.00
Benzo(ghi)fluoranthene	----	3	----
Phenanthrene + Anthracene	<0.01 <0.01	2	0.00
Benzacenaphthalene	----	2	----
Benzofluoranthene	----	2	----
Perylene	6.0	2	0.12
Acenaphthalene	0.01	1	0.00
Indeno(1, 2, 3-cd)pyrene	----	1	----
Benzo(α)pyrene + Benzo(e)pyrene	1.00 0.11	1	0.01
4H-Cyclopenta(def)-phenanthrene	----	1	----
Benzofluorene	0.08	0.4	0.00

Mutagenic Activity Accounting of Kerosene Soot $MeCl_2$ Extract

Compound	Relative Mutagenic Activity	Weight	Expected Relative Weighted Activity
Fluorene	<0.01	0.3	0.00
Uncharacterized Material	----	18.3	----
Σ COMPONENTS			0.39
$MeCl_2$ Extract	0.20	100.0	0.20

DR. MILBY: I would like to now introduce two individuals who will be talking to you. As I mentioned earlier, I must leave and dash to the airport.

Dr. Herman Kraybill, who is here and who is an old friend of mine, is the scientific coordinator for environmental cancer of the Division of Cancer, Cause, and Prevention, of NCI. He is also chairman of the NCI's Interagency Cooperative Group on Environmental Cancers, as well as having a long history as a toxicologist and pesticide researcher, Dr. Kraybill will be chairing the meeting.

Secondly, I would like to reintroduce Mr. Wheeler, who will speak to you as the last speaker of the day. Then, Dr. Kraybill has kindly consented to chair the panel discussion.

Thank you very much.

MR. WHEELER: Gentlemen, I had intended to talk to some extent about the work of Professor Lawther. However, that is not necessary since General Motors have presented his views directly. I had hoped he could have come here because I think he would have been much appreciated. Unfortunately, he has been a little bit under the weather the last few days; so he could not make it.

The bus garage work which he initiated has obviously been well covered; but there are a few points which could be made about some of the other work, in view of what Dr. Pollak was saying about the gas workers. Perhaps I could say a little bit more about that.

Pat Lawther always cites these gasworks workers as an extreme case of people saturated in polynuclear aromatic hydrocarbons. They were, in fact, retort workers on gasworks making the old fashioned coal gas. They no longer exist in Britain and probably never will again. That process if completely outmoded. However, he always cites it as a very baffling thing, because you would have expected these people to show a very much higher incidence of cancer than they did. He does not really know the reason why this is not so.

Some people suggest that it is because there has been an evolutionary adaptation in mankind to these types of materials. After all, we have lived for 100,000 years in smokey caverns, and some of us still do.

This is possibly one reason why we have a very great acceptance for carbon monoxide, unlike animals, as we found out to our cost at Ricardo the first time we did animal tests when all died of carbon monoxide poisoning. They did not live in smokey caves and never had this evolutionary adaptation. This is a controversial view which should not be carried too far in the presence of this distinguished audience.

On the other hand, I do not think it completely lifts the case against the diesel engine. I think that case still needs to be researched and answered. Certainly, we would not go along with the extremists on either side.

This problem of diesel exhaust toxicity may well not be with the PNA's; it may be other materials present, as is beginning to look very suggestive. There is a very interesting recent paper in "Combustion and Flame" (Ref. 1) in which by mass spectrometer, A. Herlan in Germany has demonstrated that there are a number of epoxy compounds which are related to the PNA's present in the combustion soot from fuel oil, not in a disel engine, but in a home heating type furnace.

Now, it is generally regarded that epoxy compounds are on the route to the action of PNA's in the human body. So, this may be a significant thing. It may be one reason why the effects of diesel exhaust soot are probably different to those of straight distillates of coal. Another thing that is baffling was that, in Britain, when we all had open coal fires, we did this type of low temperature evaporation and carbonization in open grates. Anybody who is old enough to know will know what a London pea soup smog looked like. It literally had green-yellow tarry material in the fog; but there was no real evidence for any excess lung cancer in those days. That did not arrive until 20 years after people started smoking heavily, which was during the First World War. So, that again is probably not evidence which allows us to say that the diesel engine, because it contains little more PNA than this smog, is in the clear. Diesel combustion is a different thing. It is at a higher temperature. It has different oxygen access. The whole thing is quite different. So, I would not quite go along with people who argue from one case to the other.

The one thing that bothers us, and I think it bothers the people in Britain who are interested in this area, is the relevance of extracts of soots and their application to microorganism, to what happens when a human being breathes soot as an atmospheric aerosol. It seems that we have to do some very large jumps before we have established the connection.

However, having said that, I certainly would not want to subject myself to these materials. I think that is a fact. It is a suspicious thing that these cells do behave this way. As I said earlier on in the meeting, experts in Britain that I have consulted on this point have said that they would be amazed if diesel soot did not contain mutagenic material. This is just on the basis of the galaxy of compounds which are present, many of which they would suspect from general considerations.

But, is there not some other test? Is there not some other way of exposing bacteria to the material in a more realistic way? Well, some work related to this has been done in Britain. I am not sure whether you are aware of it. They needed to expose bacteria to toxic gases. They developed a technique for exposing the whole bacteria, dry, to toxic gases in a tunnel. The bacteria used for the original test was E. coli, because it can be made dry and be blown as an aerosol through a tunnel.

The technique was a very simple one. It was to take a particular spider's web and wind this on a frame. You could wind it so that the material of the spider's web would make a mesh on this smal small chromium plated brass frame. Then you put this in a tunnel and you blew the E. coli through the tunnel, and the E. coli stuck to the spider's web. Control experiments showed that the E. coli just did not mind being stuck to the spider's web. There was nothing particularly toxic about that. There was 100 percent survival rate over quite long periods on these webs. Then they were able to expose this to gases. They were interested in irritant gases, since it was the Chemical Defence Establishment.

However, one experiment they did, which was extremely revealing and they have not gone very far with the investigation because it is not really their business, was that somebody had the idea of exposing these E. coli on the spider web frames in the night air over Salisbury plain in England in the winter and putting some controls in a climatic cabinet within the building. In the morning, the controls were 100 percent alive. The ones exposed to the external night air were 100 percent dead. This was repeated all over the country; they took it everywhere, and the same thing happened. The E. coli died in this night air.

Well, they put this down to some sort of pollution from automotive exhaust, because it was the only thing which the atmospheric dispersion experts could definitely state existed in reasonably equal proportions all over the country where they tried it. It was taken in areas where there was no industrial activity. They called this the Open Air Factor.(see Appendix). For awhile, it was regarded as an interesting material for the possible sterilization of hospital wards, if it could be in fact extracted or synthesized.

I mention this because some technique of that sort might be a better technique for the exposure of bacteria to the whole exhaust. This is something that I think is really necessary. Taking the PNA's or other toxics out of the soot would seem to be bending the whole system too far for my liking. I think it is a criticism which many have leveled against the test. That having done that, it may never relate to what happens in human beings.

I would like now to come back to a point on health effects that Phil Levins started when he was talking about irritancy. This point concerns coal miners and their objection to diesel exhaust, and they do have the strongest objection to diesel exhaust. They say that they just do not need diesel exhaust on top of the other insults to their lifestyle in the mine. They are pretty adamant about this. Anybody who was in Morgantown last fall will have gotten the message loud and clear. So, one feels that the average human being, when he smells diesel exhaust, has this bad feeling. It is not just the smell of it. It is something more than that. It is the fact that it lingers and it is with you for some time. We like to call that not the odor, but as Phil Levins said, we call it the irritancy. It has been worked on quite a bit. There is an active school in Japan based around Isuzu Motors, which has done quite a lot 66 work on irritancy. They have tried to train panels to recognize it, rather than the plain odor, which is what Phil Levins' CRC Project on the oxygenated odors revealed. This is something different. They were able to partially correlate the irritant effects with the acrolein. It is certainly the most irritant material present; but there is also sulfuric acid, SO_2, and NO_2. There is disagreement on whether NO_2 is an irritant gas or not. Some people believe that it might be a co-irritant with the sulfur compounds. Then there is, obviously, the formaldehyde. All of these things make a very nasty collection of irritant material.

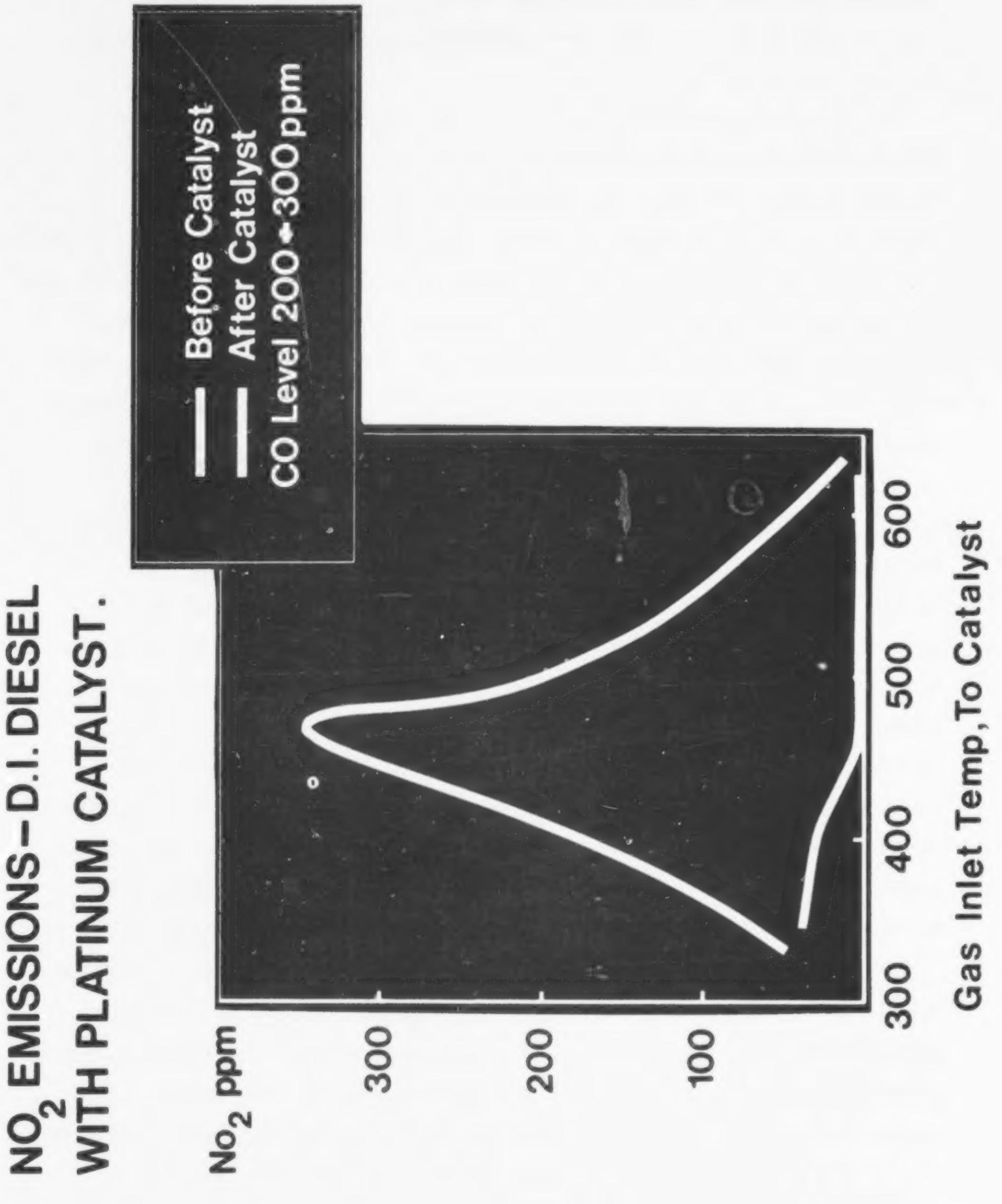
So, any work that can be done to subtract these one by one from diesel exhaust and just see where we would need to go to get a relatively non-irritant exhaust is really vitally needed. We need some sort of a test for it. We have been considering the Alarie test, which is the mice or guinea pig breathing test. (Ref. 2) This is operated quite extensively at the British Chemical Defence Establishment. They look at industrial compounds for the chemical industry. The test has been used to assess the irritancy of riot control agents and is stated to be quite good and quite repeatable. It involves a pure strain of white guinea pig. It would appear that this test could give us some results on the load speed range of diesel engines against the irritancy of the exhaust. It might allow us to run diesel engines under regimes where the irritancy is least.

Now, I mentioned nitrogen dioxide. At the Morgantown meeting, there was a considerable amount of interest in the alleged excess of stomach cancer among miners. This is not necessarily related to diesel operation, but there is some grave disquiet that the excess is not so high in lung cancer as it is in stomach cancer. One feeling was that it could be due to nitrogen dioxide from shot firing and related to in vivo production of nitrosamines in the stomach from the NO_2.

I do not know whether this is so or not, but there is one thing that is certain. That is, there are a number of modes of diesel operations which can produce large quantities of NO_2. I think we should be aware of this. We hope to publish a paper in the SAE later in the year on these modes of, not only diesel engines, bu but gasoline engines as well,pparticularly lean burning engines, which can produce quite large quantities of nitrogen dioxide. Our record so far is 400 parts per million with a fairly brown exhaust plume. That was with a platinum catalyst fitted to a Dl diesel engine.

The nitrogen dioxide before the catalyst is the lower line. It runs up to about 30 parts per million at light load. The load is shown indirectly by an exhaust temperature range. After the catalyst and at somewhere about 2/3 load with the exhaust temperature at 470° C, we run up to a very high peak of 350 parts per million. This is a warning against gaily putting catalysts on diesel exhaust. The conversion is really quite rapid, but it is very specifically around that temperature. So, what is necessary is to run the engine under regimes where you do not hit that temperature. That exhaust would be completely lethal in a mine locomotive. Even with 100 times dilution, we are around about 3 1/2 ppm.

Another thing I might mention is that there has been considerable disquiet in Britain recently.on the subject of the carcinogenicity of iron oxide aerosols. Now, every time one takes diesel soot and ashes it completely, you get a spot of iron oxide. Iron oxide is said to be a carcinogen or a co-carcinogen; but, certainly



NO_2 EMISSIONS—D.I. DIESEL WITH PLATINUM CATALYST.

a very large increase in lung cancer seems to have been revealed around a particular steel plant in Britain, which is causing concern. It has been laid down to the blowing process giving particulates of iron oxide.

Now, this is another thing. I do not want to raise scares, but these things will be raised. It is obvious that if anybody ashes diesel soot that you do have particles of iron oxide in it. These particles may also have some effect on the catalytic oxidation of SO_2 within the soot to SO_3.

In terms of health effects, I think I am with Lawther, that the case is yet unproven against the diesel; but we must be on our guard. There are some tricky points that the environmentalist can very well take hold of and will be very difficult to refute, unless we do some extra work.

Thank you, gentlemen.

(Ref. 1: A Herlan, "On the Formation of Polycyclic Aromatics," Comb. and Flame,,31, 297-307 (1978).

Ref. 2: Y. Alarie, "Irritating Properties of Airborne Material to the Upper Respiratory Tract." Archives Environmental Health, 1966, Vol. 13, pp. 433-449.)

(Written papers follow)

NHTSA DIESEL WORKSHOP
April 27 and 28, 1978
Washington, D.C.

OVERVIEW OF THE HEALTH EFFECTS OF DIESEL PARTICULATE EMISSIONS

Thomas H. Milby, M.D. and Donald V. Lassiter, Ph.D.
Environmental Health Associates, Inc.
Berkeley, California

As Professor Pitts correctly pointed out in his opening presentation, to establish the nature and magnitude of a health effect, one must have reliable information on both dose and response. Professor Pitts pointed out that his concern was on the dose side; our concern, is on the response side.

As the preeminent respiratory physiologist and toxicologist, Dr. Mary Amdur, stated almost a decade ago, "the term 'particulate matter' as such does not represent a unified concept in the toxicological point of view...." The reality of this simple statement is brought home quickly and forcibly to anyone interested in the complex relationship between airborne particulate matter and human health effects. When the experimentalist (such as Dr. Amdur) devises a laboratory experiment to examine the physiological or pharmacological response to exposure to particulate substances--whether the experimental subject be man or laboratory animal--he or she has the capability of rather precisely characterizing that exposure in terms of particulate size and chemical composition and exposure concentration. In addition, the experimentalist is generally free to select the most sensitive recognized indicator of response, whether it be small changes in pulmonary mechanics, respiratory gas exchange, pulmonary diffusing capacity, etc. The air pollution epidemiologist, on the other hand, has for the most part, been forced by lack of technological sophistication to settle for relatively simple measurements of airborne concentrations of ambient particulate matter with little knowledge of particulate size or chemical composition. To further complicate the job of the air pollution epidemiologist, until only recently, the most sensitive measures of pulmonary impairment have been laboratory procedures unsuitable for field application. Thus, restricted by the availability of sensitive instrumentation, both in terms of estimation of dose and measurement of response, it is little wonder that we know so little about the effects of ambient concentrations of airborne particulates on human health.

In any discussion of response to airborne particulates, it is not altogether artificial to divide response into carcinogenic and noncarcinogenic response. Because time is limited, I will confine my remarks here to a consideration of the carcinogenic effects of airborne particulates because, at least in connection with diesel exhaust emissions, carcinogenesis appears to be without doubt the most troublesome of the two groups of effects.

You have heard a good deal from the preceding speakers on the issues of characterization and measurement of diesel exhaust emissions and factors affecting human exposure. Thus, we are aware that diesel exhaust is an extremely complex mixture containing gaseous, liquid, and solid components with the relative amounts of the total exhaust contained in each of these phases dependent upon the temperature, vapor pressures of the individual components, and amount of dilution of exhaust. We know also that one finds in this mixture the products of complete and partial combustion of the fuel and lubricant, as well as the unburned fuels and the lubricants, themselves. The problem is further complicated by the fact that fuel supplies vary, and by the fact that engines are not run under a constant set of conditions.

To put into perspective the quantities of diesel exhaust particulate that enter our environment yearly in relation to other major sources of particulate, I call your attention to Slide No. 1. The information on this slide was prepared by the Midwest Research Institute in 1971 for the Environmental Protection Agency. You will note, of course, that motor vehicles--both gasoline and diesel powered--contributed a very small percentage of overall particulate air pollution. As all of us recognize, of course, the importance of a particulate is only partially gauged by its concentration in the air. Of much greater relative importance are such characteristics as particle size and chemical composition. Thus, in terms of health consequences, there can be little

Slide 1

SIGNIFICANT SOURCES OF PARTICULATE POLLUTION

Source	Emissions (tons/yr)	Total
A. Natural dusts		63,000,000
B. Forest fires		56,400,000
C. Transportation		
1. Motor vehicles		
a. Gasoline	420,000	
b. Diesel	260,000	
2. Aircraft	30,000	
3. Railroads	220,000	
4. Water transport	150,000	
5. Nonhighway use	120,000	1,200,000
D. Incineration (Municipal, etc.)		931,000
E. Other minor sources		1,284,000
TOTAL		122,815,000

Source: Midwest Research Institute

question that motor vehicle-evolved particulates are more significant from a health point of view than are such things as natural dusts and particulates evolved from forest fires, despite the fact that the latter two sources account for a considerably larger percent of the total airborne particulate load.

We realize that it would be naive at this juncture to suggest that the polycyclic aromatic hydrocarbons, benzo-(a)pyrene (BaP) is the sole or even the most important carcinogenic substance to be found in diesel exhaust. Nonetheless, more scientific investigation as well as more speculation has been focused on this compound as in occupational and environmental carcinogen than any other substance likely to be found in diesel exhaust.

Slide No. 2 is a compilation of BaP concentrations in various atmospheres. I would like to call your attention to several entries in this table. First, the figure for BaP in average U.S. city ambient air of 6 micrograms BaP/1000m^3 of air. One can find urban ambient air estimates for BaP ranging from considerably less to more than twice this figure. The second entry I would like to highlite is the figure for British gas works - worker area. As estimated by Lawther and his colleagues, concentrations of 3000 ug/1000 m^3 are not uncommon. Finally, in the same British gas works, BaP concentration in retort fumes may reach 230,000 ug/m^3. While these figures are of some interest, it is important to attempt to bring them into perspective in terms of their

Slide 2

BaP CONCENTRATIONS IN VARIOUS ATMOSPHERES

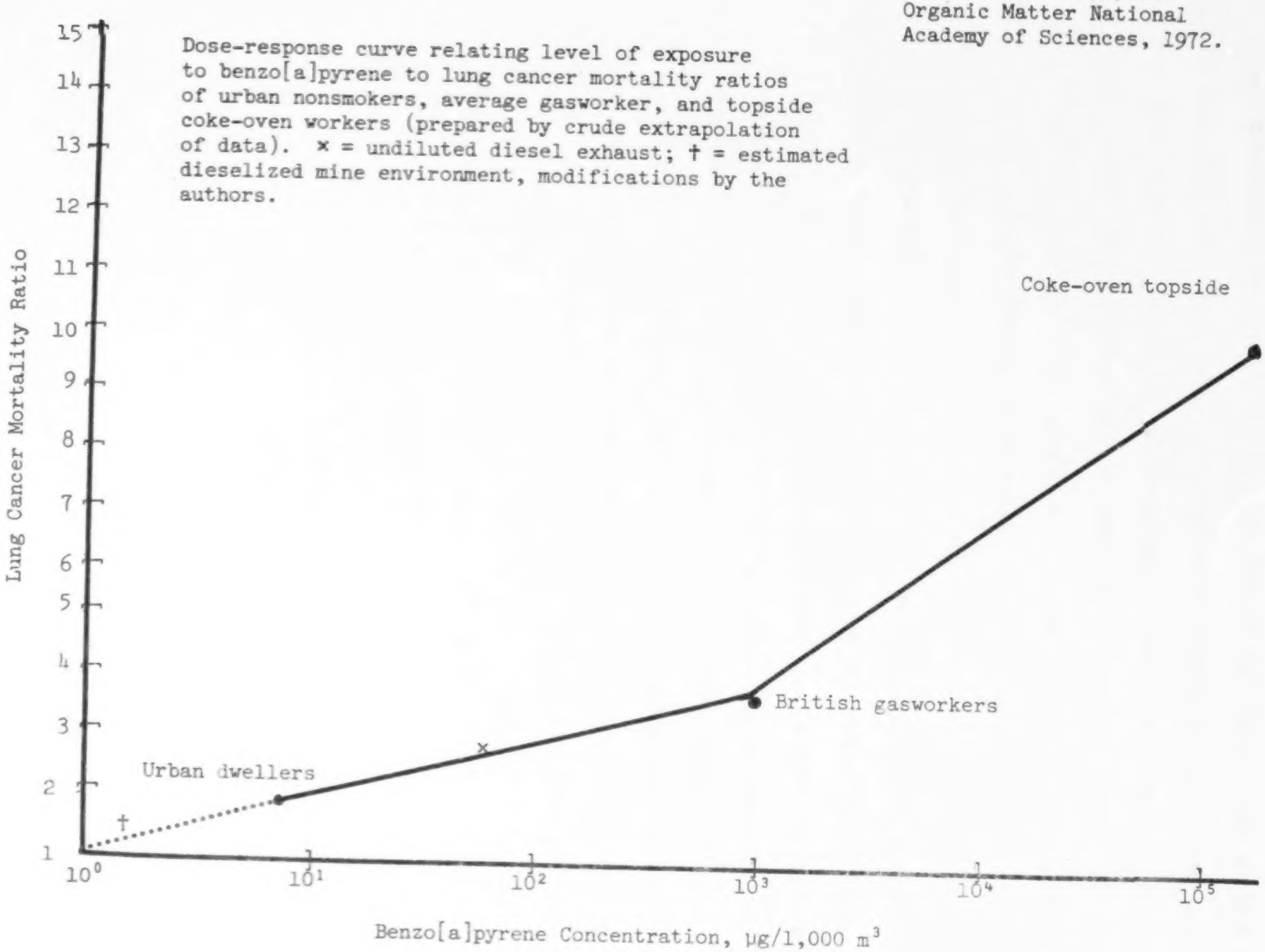
	μg BaP 1,000 M^3
Coal-tar roofing kettle area	6,000,000
Gas works retort fumes	230,000
Coal-tar-pitch working area	75,000
Roof-tarring area	14,000
British gas works - worker area	3,000
Bus garage	80
Boston Sumner tunnel: exhaust air	69
Boston Sumner tunnel: intake air	2.6
Average 100 U.S. cities, 1958	6
Grand Canyon Park, Arizona	0.04

Source: Sawicki, 1967

meaning in terms of health consequences and also if possible relate them to diesel exhaust emissions.

Slide No. 3 is a dose-response curve relating level of exposure to BaP to lung cancer mortality ratios in urban nonsmokers, average gas workers, and topside coke oven workers. This curve was originally published in the National Academy of Sciences (NAS) Monograph entitled, "Particulate Polycyclic Organic Matter," released in 1972. Professor Pitts, by the way, was chairman of the NAS Committee which prepared this document. Added to this curve are the "x" and "+" signs which we placed to show, respectively, our estimates of BaP levels found in undiluted diesel exhaust and in the underground mine environment, based on data not presented here. With respect to response, it is worth commenting on several points identified on the curve found in Slide 3. The well-recognized two-fold difference in U.S. urban-rural lung cancer rates is the basis for the point identified as "urban dwellers." (The NAS authors used 8 mg/1000 m^3 as their estimate of urban BaP levels). The point identified as "British gas workers" represents an 8-hour exposure to the 3,000 ug/1000 m^3 occupational exposure estimate for British gas workers which has been reduced by the NAS authors by a factor of three to 1000 ug/1000 m^3 to establish an equivalency with urban atmospheric exposure over a 24-hour period. The point identified as "coke oven topside" represents an extrapolation from measurements taken above British gas works retorts (216,000 ug/1000 m^3) corrected for a 24-hour day exposure (reduced by

Slide 3



Dose-response curve relating level of exposure to benzo[a]pyrene to lung cancer mortality ratios of urban nonsmokers, average gasworker, and topside coke-oven workers (prepared by crude extrapolation of data). x = undiluted diesel exhaust; † = estimated dieselized mine environment, modifications by the authors.

Source: Modified from Particulate Polycyclic Organic Matter National Academy of Sciences, 1972.

a factor of three) to 72,000 ug/1000 m^3. It is necessary to make this extrapolation from British data because there are no data on coke oven topside concentrations of BaP in the U.S. What is known, however, is that there is a tenfold excess in lung cancer mortality among U.S. coke oven topside workers.

In summary, then, it is safe to say that much additional research needs to be undertaken to bring us to a workable understanding of the potential health hazards associated with exposure to diesel generated particulate matter. That under certain circumstances, diesel exhaust may contain mutagenic, and thus possibly carcinogenic, substances has been shown. The question remaining from the standpoint of the health scientist must be: What is the significance of these findings in terms of the health of populations exposed to diesel exhaust emissions?

MRC
Medical Research Council

MRC Toxicology Unit, Clinical Section
St.Bartholomew's Hospital Medical College
Charterhouse Square, London EC1M 6BQ

telephone 01-253 1537 & 3378

reference PJL/JB

19th April 1978

Miss Joan B. Claybrook,
Administrator,
National Highway Traffic Safety
Administration,
400 7th Street SW,
Washington DC 20590,
U.S.A

Dear Miss Claybrook,

Dr. Jaroslav Vostal of General Motors telephoned me the other day about your plans to hold a 'workshop' on the topic of diesel engine particulate emissions and similar matters on 27th and 28th of this month. He was anxious for me to be present to present some of our findings of 20 years ago, but unfortunately my diary was already booked up. He asked me if, as an alternative, I could let you have a brief note on our work and opinions. I enclose such a statement in the hope that it will be helpful.

Dr. Vostal also asked me to let you know my 'official' positions. I am Head of the Clinical Section of the Medical Research Council's Toxicology Unit. I am also Professor of Environmental and Preventive Medicine in the University of London, and Physician-in-Charge of the Department of Environmental and Preventive Medicine. From 1955 until recently I was Director of the Medical Research Council's Air Pollution Research Unit before we joined the Toxicology Unit.

I trust that these details will be adequate.

Yours sincerely,

P. J. Lawther, MB, DSc, FRCP.

Enc.

cc Dr. J. Vostal

A NOTE ON PARTICULATE MATTER EMITTED BY DIESEL ENGINES WITH REFERENCE TO WORK DONE IN LONDON BY THE MEDICAL RESEARCH COUNCIL AND LONDON TRANSPORT

Two main types of particulate matter may be found in the exhaust products from diesel (compression ignition) engines: a whitish, irritant, lachrymatory fume may be emitted for short periods on starting from cold; visible fumes ranging in colour from bluish to dense black may be emitted later when the engine is warm. The whitish mist is composed largely of minute droplets of unburnt fuel and may be a transient nuisance in garages; the fume emitted later is almost wholly carbonaceous and consists of minute (less than 1u) particles which are usually aggregated. The amount emitted depends on running conditions, load, proper adjustment, and the state of maintenance of the engine. When properly adjusted, well-maintained, and not overloaded, a small puff of visible smoke may be seen on moving away after which the exhaust should be barely, if at all, visible. Such is the case in London Transport's large fleet of diesel-powered buses, on which many studies have been done. No lead is emitted by diesel engines.

In the early 1950's there appeared reports that polycyclic aromatic hydrocarbons (including the well-known carcinogen benzo (a) pyrene) had been found in the smoke from a diesel engine. These findings were hardly surprising since these compunds are the pyrolysis products found in the compounds resulting from the inadequate combustion of any carbon-containing fuel and may be found in many materials varying from toast and smoked food to meteorites. By far the commonest source is coal smoke which used to be major air pollutant in many cities. The finding of carcinogenic compunds in diesel smoke lead some to suspect that diesel exhausts might be the cause of the notorious epidemic of lung cancer which we now know to be due overwhelmingly to the smoking of tobacco; experiments on animals were instigated in some laberatories but have yielded no worth-while results. The rise in the incidence of lung cancer started long before the appearance on the streets of diesel engines, nevertheless it was considered to be an urgent task to study the distribution and possible effects of diesel exhausts on man. The Medical Research Council's Air pollution Unit and London Transport collaborated closely to scrutinise mortality and morbidity data and in surveying bus garages for various pollutants. The MRC Unit subsequently did much work on pollution from traffic in tunnels (Waller, *et al*.,1961), and in streets (Waller, *et al*., 1965) as well as on exhaust products collected from engines on test benches. The work continues; some results are briefly repprted below:-

London Transport has always maintained excellent records of the health of its workers, including information from pre-employment and later follow-up medical examinations, sickness-absence during employment, and ultimately cause of death either in-service or subsequent to retirement. Many of these records have been maintained on punch cards, and for some years now have beeh transferred to magnetic tape. While the main purpose of these records is for administrative control and for matters connected with their pension scheme, they have provided a valuable base for many research studies done either by the LT medical Staff or by them in collaboration with the MRC and other bodies. Among these studies have been ones connected with the possible adverse effects of exposure to diesel fumes. Raffle (1957) published a paper commenting on a number of aspects of studies of the health of LT workers and within this he presented data on the incidenceof lung cancer during the period 1950-54. He was able to show that the annual rate (a composite rate based on deaths, ill-health retirements and transfers to alternative work) in each category of workers was of the same order of magnitude as the death rate over a similar period among the general population of London, and for most categories it was, in fact, lower than was expected. When the figures were arranged in order of likely exposure to diesel fumes there was no indication of any relationship between exposure and the lung cancer rates; thus, engineering workers in trolleybus depots (where there would be no special exposure to fumes) had the highest rates and central London bus drivers (who would be exposed to the worst street traffic fumes) had the lowest rates. Engineering staff in bus garages (where concentrations of diesel fumes were likely to be especially high) occupied an intermediate postition. A further analysis covering engineering staff was done for four geographic areas of London. The rates were found to be relatively high in the NE and SE areas where population densities were high, and where there was reason to believe that pollution by coal smoke would be greater than in other areas.

The early study showed therefore that there was no special lúng cancer risk among the LT workers irrespective of their job. Such variations as were seen looked as though they could possibly be related to general air pollution rather than to any specific exposure to diesel fumes, and in the concurrent environmental sampling work done by the MRC Unit (Commins, et al.,1957) it was shown clearly that concentrations of benzo(a)pyrene in and around bus garage were dominated by emissions from coal fires in the neighbourhood. The small amounts coming from the buses were detectable only when general background levels were low as on warm days during the summer months, and it was concluded that, although large amounts of black smoke were dispersed at times from the buses when they were being manoevred inside the garages, this smoke contained only very small amounts of benzo(a)pyrene and other polycyclic hydrocarbons. This finding was confirmed by by further studies on emissions from engines running under controlled conditions on test beds at LT research laboratories, and only when these bus engines were grossly over-fuelled to provide dense clouds of black smoke that would be intolerable in normal working condintions, could appreciable quantities of polycyclic hydrocarbons be detected. Still more work on the polycyclic aromatic hydrocarbon content of smoke from diesel engines was done at this time by the firm CAV (makers of diesel injection equipment) in their research laboratories, and this work confirmed our findings that at all normal operating conditions the yield of benzo(a)pyrene was extremely small.

In Raffle's lung cancer study it was recognised that there was no control for the effects of smoking. It had not proved to be practicable to examine the smoking habits of the cases of lung cancer or of other employees, but there was no reason to believe that they differred substantially from those of other working men in the same age range. It seemed possible that the small variation in lung cancer rates seen between the operational and occupational categories might have been related to differences in smoking habits, if only because there were some differences in restrictions on smoking whilst on duty. Until 1952, for example, there had been an embargo on smoking in bus garages (because of fire risks while some petrol buses were still in use). This restriction had not been enforced in depots dealing with electric trolley buses only; among staff employed in trolley bus garages the lung cancer rate was relatively high. Only minor differences in smoking habits would have been needed to produce differences in lung cancer rates of the order of 50% such as were seen to occur between trolley bus and diesel bus garage workers. One further point that has been raised in connection with the Raffle's study is that even if there were any carcinogenic effects of exposure to diesel fumes they may not have become manifest in the period 1950-54 since diesel engines were then relatively novel. LT buses were originally powered by gasoline engines in the 1920's and the process of replacing them by diesel vehicles had stared a few years before the war. It was not until 1952 that their fleet became entirely diesel powered; by then all electric tram services had also been replaced by diesel buses; trolley buses were retained for some further years before they too were replaced by diesel buses.

All the evidence on the relationship between lung cancer and smoking, and also that relating the disease to exposure to specific materials used in industry, indicates that many years elapse from first exposure to the carcinogen and the eventual diagnosis of the disease; the period may be about 30 years, but may be less in the case of especially potent compounds. If the diesel 'age' did not begin until the late 1930's it might be necessary to wait until the 1960's or 1970's to check whether the diesel engine has had any discernible effects. With this point in mind arrangements for collecting all available information on lung cancer cases among selected groups of LT staff were continued on a long term basis. Data from a period of 25 years have now been assembled (from 1950-1974) and again comparisons are being made between LT rates and those found among the general population, and between the various LT categories. This study is being undertaken jointly by LT and the MRC Unit. One serious limitation is still the lack of information about smoking habits for this is being collected retrospectively by gathering information on deaths and sickness without any prior enquiries about smoking. Despite this limitation, it would still seem that if there were occupational risks of an important magnitude their effects would be manifest if one were to assume that smoking habits of the populations studied were reasonably similar.to those of the general public.

The present situation may be described as follows: During the period 1950-74 as a whole lung cancer rates among LT staff are a little below those seen in the general population of London. There are still small differences between categories but these are smaller than those seen in the data from 1950-54 alone. Indeed there is barely any difference at all between the categories of bus drivers, bus conductors, engineering staff in the garages, and motormen or guards on the Underground. Staff at the LT Central Works had slightly lower rates than the rest. There is nothing in these figures to suggest that there is any appreciable risk associated with exposure to diesel fumes. The slightly below average rates are as would be expected in an employed population subject to pre-employment medical screening, but if there were any real risk the results should be reflected in some excess lung cancer among the workers employed in bus garages; from a study of the presentsfigures they seem to be in line with most other groups. Nor is there any indication of any differential trends through the years. Lung cancer death rates were increasing among the general population (of Males) in the 1950's and into the 1960's but more recently a gradual decline is evident. This change fits basically with trends in smoking and especially with the swing towards the use of filter-tip and low-tar cigarettes. The LT group is to small to enable one to follow yearly trends within different categories but the general pattern seems to follow that of the general population and is probably dominated by changes in smoking habits. The possibility that the very substantial decline in pollution of town air by polycyclic hydrocarbons from coal fires (especially notable in London) might also have some bearing on the declining trend in lung cancer deaths must be borne in mind, but this is unlikely to be a major factor.

At the risk of stating the obvious it must be said that the use of diesel-engined vehicles in cities would reduce substantially pollution of the air by lead and carbon monoxide - two pollutants about which there is constant worry.

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DR. KRAYBILL: I have the onerous task wished upon me by Dr. Milby of chairing this Panel. I wonder if the panelists would please come forward.

While we are convening up here, I would like to make just a few brief remarks.

Since this is an area in which I have no great expertise and not being an expert on diesel emissions, that gives me license to offer some unbridled remarks.

At the National Cancer Institute, however, we have intensified our efforts in areas such as water pollutants and food contaminants. Sad to say, we have not done a lot of work in the area of what I call air pollutants; but I would like to make a very few brief remarks in looking over the material that we have and some of the reports from the National Academy of Science. Then, I would like to get back to Dr. Pollak's remarks, because I was rather placid sitting here today until I heard the few remarks he made. That generated some thoughts on my part.

Certainly, experimentally we have shown that tars collected from the air are carcinogenic to animals. Tars collected from air transform cells in culture. Therefore, in the air there must be carcinogenic materials that have an effect on perhaps the lungs and other target organs. There is little evidence that any of these are carcinogenic. That is, some of the gaseous materials like CO_2, SO_2, and NO_2 are in and of themselves not so;;but in conjunction with other materials, as I will indicate in a few minutes, they could be synergizing other chemicals.

There is little evidence that any of these are carcinogenic, with the exception of particulates which may act as irritants or react synergistically with benzo(a)pyrene and the polycyclic aromatic hydrocarbons in general. When I think of particulates, of course, I think of asbestos, asbestosis and mesotheliomas.

Certainly, benzo(a)pyrene is the notable carcinogen of polycyclic aromatic hydrocarbons. Benzo(a)pyrene constitutes only a fraction of the total carcinogenicity of air pollutant tar. I was interested in Mr. Wheeler's last remarks, when he said we should look beyond PNA's. I think that is quite true.

The non-PAH fraction is a potent carcinogenic fraction. It has ability to transform cells. In Los Angeles County, 42 percent of the particulate emissions were caused by motor vehicles. In downtown Los Angeles, virtually all the benzo(a)pyrene in the air is from automobiles.

Now, the question I would raise is, if we increase the number 66 diesel fuel burning engines, will we increase substantially the particulate emissions? In other words, you can see that I am more concerned about the particulates than I am with the polycyclic aromatic hydrocarbons. Why do I say that? Because I have been the polycyclic aromatic hydrocarbons proliferate through our environment. It is in our food supply. It is in our charbroiled steak. It is in our water supply. It is just everywhere. So, the particulates are the agents which interest me.

The question is will we increase the lung cancer rate over and above cigarette smoking by such emissions? I do not thinkwwe have the answer to that yet. Will we enhance the opportunities for synergistic action of benzo(a)pyrene and other polycyclic aromatic hydrocarbons on these particulates by adsorption for an exponential increase in lung and other organ cancer rates?

The bulk of the benzo(a)pyrene now in the air is associated with particles that do reach the lung. I think that has been amply demonstrated in some of the papers here this afternoon, which indicated that it can get to the lung bed. The carbonization workers in British gas works had a lung cancer rate 80 percent higher than for all men in England and Wales. There was a slight increase in lung cancer among non-smokers in urban compared to rural areas. I think you are well aware of that story, which would seem to imply that perhaps urban living, living in New York City, is less desirable than living out in a rural area.

There are other cancer sites which one might consider, too. We all talk about lung cancer; but ultimately, we have to think about other sites, such as the oral cavity, the larynx, the bladder, the esophagus, the pancreas, and the kidney.

Now, the question is, what would be the effects of particulates and benzo(a)pyrene on those components of our population who, for genetic reasons, have variant levels of inducible aryl hydrocarbon hydroxylase? In other words, we have to keep thinking about the susceptible members of the population. Getting back to a thought that Dr. Pollak was talking about earlier, we have to ask whose ox is being gored?

Now, the benzo(a)pyrene, with this enzyme present, can we produce chemically reactive electrophiles? The air pollutants maximally induce this AHH system. So, I think that is probably the answer to why some people live to 85 or 90 and smoke cigarettes like smoke going up the chimney and never come down with bronchiogenic carcinoma. They probably picked the right grandparents. They have a genetic background here to preclude that happening, due to these enzymatic systems.

Thus, for those who are genetically inducible, even low levels of carcinogens in the lung may have these carcinogens optimally transformed to their active state where it can do the most damage.

Now, the next question. How much do these particulates and the particulates plus the polycyclic aromatic hydrocarbons, which are increased in the atmosphere, increase the cancer burden? It would seem a prudent public health control measure, and here I am showing my bias, to insist on a diminution of such increased carcinogenic insults, especially when we are developing postures and moving in a direction in the reduction of other pollutants, such as water carcinogens.

I, with several others in working with EPA just last week, developed a position paper. We are trying to shoot for a standard of 100 micrograms per liter of trihalomethanes in our drinking water supply. I think that is a logical step to take.

We do not know yet what these low levels of chloroform, dibromochloromethane, dichlorobromomethane, and any of these other chlorinated materials are doing; but we are starting to see some statistical associations between the level of carcinogenic contaminants in our water.

An interesting observation is that, in Philadelphia's Zoological Garden, out of 21,000 animals they necropsied over a 68-year period, they showed an increase in incidence of lung tumors in avian species. This would seem to indicate or give some evidence on the increase of malignant neoplasms probably attributable to atmospheric pollutants.

Dr. Milby asked me to say something about our approaches, and I will dwell on that briefly. We are using, as stressed here today, certain in vitro systems, such as bacterial systems, point mutation, cell transformation, cell cultures, DNA repair systems. This work is all under the direction of Dr. Virginia Dunkel. We are spending about $5,000,000 on methodological approaches. Up until recently, we were not able to say that we could adopt any of these systems as a replacement for in vivo systems. We merely use these systems as a prescreen; but within the last month now, we are going to take some of these methods and use them to prescreen for those chemicals that we select to put in what we call a carcinogenesis bioassay.

The carcinogenesis bioassay costs about $200,000 per chemical, if you are doing a feeding study, and about $300,000 if you are doing an inhalation study. As you know, inhalation facilities are quite limited in the United States.

So, the in vitro procedures, as desirable as they are and as rapid as they are and cheap compared to the other procedures such as the in vivo methods, we are not quite ready to standardize on these as yet. Some people say the Ames system may correlate 80 to 85 percent with the in vivo test results.

Now, the diesel fumes, as I said earlier, the particulates seem to me to be quite important. Why am I concerned about particulates? I guess it goes back to the story of the asbestos particles. Here size is a limiting factor and very important.

I think we have pretty well established the story on asbestos and mesothelioma. Certainly, all of us know that Dr. Selikoff has done a tremendous job and given a lot of publicity to that side of the story; but we must look at some of these other particulates in our environment. Shabad's work in Russia is quite instructive, I think. He took asbestos and had it coated with benzo(a)pyrene and showed a large increase in tumors over that of asbestos or benzo(a)-pyrene alone. So, here you have particulates which can get coated and which can get into the bronchii or the lung bed and start their action.

Then you have sulfur here which goes to SO_2, and that is one of the gaseous materials you mentioned here today. So, SO_2 plus benzo(a)pyrene could be a synergistic response that could enhance tumorigenesis.

Getting back to Dr. Pollak's remarks. I like to talk concepts. I would like to say at the outset that everybody recognizes that there is no such thing as a riskless society. There is no such thin thing as zero risk. There is no such thing as absolute safety. It is like a pathologist said, "Every day you get up out of bed, you take quite a chance." You may walk across the street and get hit by an automobile; but we have to deal in terms of what we call relative risk. We have to talk about relative risk. We have to talk about risk benefit; but when we get into a discussion of benefit, the benefit side of the equation is not that highly developed. Many of us have not made a very good case on the benefit side. We need to do a better job. When the aspect of benefit comes up, they say, "Yes, but whose ox is being gored?" For whose benefit? Mine? Yours? Industry's? Whose?"

The other thing that you mentioned was also the aspect of threshold. Now, this is something that I am interested in. In one of the reports of the World Health Organization, they said that one might envisage a threshold; but they say that there is no scientific method to prove threshold. Until we prove instructively and constru structively, biologically, that there is such a thing as a threshold, our mathematical friends and statisticians with their mathematical models are going to extrapolate down to zero, and they are going to make these estimates for us.

What we have attempted to do and one of the approaches is to use research probes, or what I call presumptive negatives or biochemical intermediates. Well, that sounds odd; but we are going to take Vitamin C and run it through the bioassay. We are going to take some other vitamins and some minerals and some of the Krebs cycle chemicals, like citric acid, tartaric, succinic, fumaric, et cetera, and put them in and feed them at high dose. Like Dr. Walter Mertz said at Beltsville, obviously, if you test all the essential minerals, you are going to get tumors at a very high dose. I have no doubt about it.

So, recently, we now have on the books that arsenic is a carcinogen. Calcium is a carcinogen; but a scientist at Cornell got ultimobranchial tumors in bulls at five times the RDA((Recommended Daily allowance). The cows did not get it because they lactate. We have, as a carcinogen xylitol which is in chewing gum, and this endogenous chemical is part of the glucuronic acid pathway.

Sucrose (table sugar), at 20 percent in the diet, produced kidney tumors. Now, I do not know whether if one takes biological intermediates and shows that at very high doses you can get tumors and down lower you do not, that this will convince anyone.

As you proceed along the dose response curve, you will see a zone of what we call detoxification. Then, as you ascend on the curve, you would obtain a zone of what we call intoxication.

Some of these high doses are producing a high stress on a target organ and on the cells. They are extrapolating downward from these results.

The work on chloroform was done at 180 milligrams a kilogram, and the next dose was 90 mg/kg. Roe in England got nottumors at 60 milligrams a kilogram for chloroform. So, some of our people said it was a defective study. I am not so sure it was. In this latter study, they saw a few tumors in the kidneys. Well, they say if you come downwards from 90 down to 60, you may not see any tumors at all. Well, I said if we go to 500, you may see a zero. If you go to 1,000, you may still see a zero incidence. If you go to 10,000, you may still see it. So, really going down from 60 to 30 is like going from here to eternity; but to study a probably response down to 100 micrograms per liter is like going from here up to Africa. We, thus, need newer approaches for this problem.

The way I think we are going to work ourselves out of this thing is to look at biochemical parameters. Look at metabolites. Look at the level of these chemicals in the liver and in the kidney and in other organs and look at the metabolites and use for extrapolation downward the biochemical parameters. Look for necrosis and things of this sort in the liver to see where the appearance point is in the changes in pathology, to see if we can predict. I think that is our only salvation. Until we do that, they are going to say, that cancer is an irreversible reaction and it has no threshold.

Finally, on epidemiology, getting back to what Dr. Pollak said, epidemiology is certainly not a sensitive system; but it is about the best we have, unless we want to sit around and count bodies, and we cannot do that. So, we have to use animal studies, as crude as they are, and as crude as some assays may be. The direct evidence on carcinogenic risk of an agent or chemical from epidemiological studies is desirable, but most usually unavailable. Whereas such approaches may deliver a strong indictment on hazards which may espape other determining procedures as well as providing early warning signals, epidemiological studies cannot be used to predict or assure safety.

For example, data on effects is not available until humans have been exposed, unfortunately. Then, when they have been, it is not until in some case mortalities or morbidities have been reported. The case with vinyl chloride in angiosarcoma of the liver was a sad story, although some people said we were not really observant. If we had looked at Maltoni's data, the animal data was telling us something about the angiosarcoma of the liver; but there are so many instances where we wait until we see the mortalities before we get evidence as to whether this particular thing is a carcinogen.

Invariably, if the exposure is widespread, such as DDT, how would you do a study on DDT, because it is global? Where would you get your cohort. I guess the only place you could get it would be o on formulators who worked for 20 or 30 years and have had a high exposure. It does not appear that DDT is a carcinogen. It is a carcinogen to the mouse, but nottto man. We have been exposed to it for 36 years, and we have not seen a large rise in liver cancer with DDT. Perhaps we have not looked adequately.

Another feature in the epidemiological pursuits is the complex problem of the identification of small deviations in a common response or effect, which could be most important in a determination of incidence in a large population. Epidemiological studies are, nevertheless, ancillary to, and a reinforcement for, the determination of errors in data derived from animal experimentation. While animal studies are essential to predict potential hazard and to evoke some public health concerns, and that is all they do, they are indicators.. They do provide a mechanism for warning before the more awesome experience of counting mortalities in man from exposures to carcinogens.

Thus, I would like to say that epidemiological studies are invariably referred to as the last line of defense in verification of the potential public health hazards. I have talked too long, and I would like to turn the session over now to the panelists. Would you direct any of the questions that you have to the panelists at the table?

Any questions?

MR. GIBBONS: I would just like to point something out on Dr. Milby's remark about the healthy worker effect. Earlier, Dr. Milby commented on Dr. Vostal's presentation of one of Dr. Lawther's papers, a study of health effects of diesel in the London bus system. The healthy worker effect was partially, at least, taken into account in that paper. The author, Dr. Raffle, specifically commented on that phenomenon and displayed the ways in which that was taken into account. In other words, transfers, retirements that ended in death after service were included in the cohort.

DR. VOSTAL: Thank you very much for the comments. First of all, I would like to apologize to Mr. Dick Wheeler. I did not know that the program would also include a presentation of the European opinion on potential health effects of diesel exhaust. Therefore, I took the liberty to mention the data, which were collected in a splendid study in Great Britain. I think I can still use the adjective splendid for a perfect study, although the more we are away from the time when the data was collected, the more we can recognize that there may be many weak points. For example, there could be a theoretical objection that not enough attention has been given to the smoking habits of the people who were followed up. There might also be other factors involved; for example, somebody could say that the latency period has not been adequately long. So, I perfectly agree with what Mr. Dick Wheeler mentioned this afternoon, that we still should not consider the diesel question foreclosed. On the contrary, we should accumulate as much data as possible in the shortest amount of time. This applies to all the usual approaches, the epidemiological data, clinical experiment on volunteers, the animal data and any other type of screening test.

I would like to use this opportunity to correct a statement mentioned in the previous comments. I have heard in the discussion by Dr. Pollak that I tried to degrade the role of the Ames test. I would like to emphasize that this was not my intention at all. I feel that the discovery of the Ames test was a significant step forward. It is a test which we need to use for wide screening for potential mutagenic effects, even if we recognize that there might be weak points in the relationship between the mutagenicity and carcinogenicity. I also think that its results should serve mainly as a stimulating factor to do more studies and to identify what are the exact links between the mutagenic effects and between the potential carcinogenic or teratogenic effects, rather than to claim it as a final proof for regulatory action.

I think we should all compliment Dr. Thilly on the results of his study presented here today; but I feel we need many more studies on this subject before we can use the mutagenicity tests in our predictions of the health effects on human populations.

DR. POLLAK: Well, I would just like to respond to this idea about the Ames test being a valid carcinogenic indicator. The idea that it might serve as a valid screening tool and the fact that it has a certain degree of correlation to carcinogenicity in animal studies and perhaps in human studies makes it just that. It is only a screening tool, and a poor one at that. The fact that it actually might indicate further certain biochemical mechanisms associated with carcinogenesis is interesting from a basic or pure scientific research point of view. What we do not know about cancer is pretty near 100 percent. Therefore, this could give us an insight into a way to approach it. Fine.

If you look back at the record, the November 12 EPA release which you quoted about the possible effects on garage workers and so on, in enclosed garages; and I do not really know who really works i in closed unventilated garages on automobiles, but I suppose some do; but the effect of the EPA release, which was based strictly on the Ames test was to actually cause a certain degree of hysteria in automotive workers. Now, that was an obvious misuse. Even though EPA tried to ameliorate some of the potential of its misuse, it was misused by the press to the point now where there is this general overriding belief throughout the non-scientific community, based on the Ames test, that diesels have this proven carcinogenicity. That is the catuion to be gotten out very emphatically about the Ames test and the misuse of it.

It goes further. I tried to identify this in my talk. The idea starts creeping through the population; and then, suddenly, the people who promulgate a very reasonable technology, which seems to meet certain other needs such as economy and so on, are suddenly on the very defensive side of the fight. That is actually all through a misuse of a test that has very limited function in a scientific sense.

DR. KRAYBILL: Dr. Battigelli, weren't you going to join us?

DR. BATTIGELLI: I was going to listen.

DR. VOSTAL: May I make a comment here? I think we have heard from the question and the last presentation by Mr. Wheeler that we may be concentrating too much on polynuclear aromatic hydrocarbons, and we have not looked for some other factors which could still be hidden in the diesel exhaust. Mr. Wheeler has mentioned one, existing in the form of iron oxide in the ash of the particulate. If I remember all the data accumulated in experiments using inhalation of iron oxide and presenting iron oxide as a potentiator of other carcinogens in animals experiments. I feel that the concentrations used in the experiment were very high. I do not exactly know how high the concentrations are of iron in the diesel particulates, and I hope that you will help me in this respect and correct me if I am wrong.

Second, wouldn't it also be possible that the form of the iron which is presently in the particulate may be completely different from that of the iron oxide. As a matter of fact, we expect to see theiiron oxide form only after the full combustion of the entire particulate, isn't it so? So, maybe it might not be the same biological effect. Could you comment on that?

MR. WHEELER: Not really, except that iron is definitely present. The actual iron which is in the blowing steel is almost certainly of a different form, I would think, which is the one implicated in this British scare at the moment.

DR. VOSTAL: But this is a completely different story.

MR. WHEELER: It may be a completely different story. This story has just come out in Britain, where a local doctor at the steel works has suddenly revealed that there is a very large excess of lung cancer in the district around the steel works. Unfortunately, it is one of the events where the steel works was there and the population moved up to it in an uncontrolled way. He has plotted contours of the people that have suffered, and there has been quite a large death roll already. It seems fairly conclusive; but they are only hinting at the moment that it is iron oxide dust which is the cause.

At the moment, there seems to be no other cause; unless, of course, the steel works does put out quite a quantity of combustible fumes. I only threw that one in because somebody is going to think about it. I am sure that you will think of some way where this does not happen, but we see this in our thermogravimetric analyzer samples. When you burn all the soot, you get a little bit of wear products. I suppose the lesson is that we have to make engines that do not wear.

DR. WHITFORD: I am Bob Whitford of the Transportation Systems Center. First of all, I would like to thank not only this panel but all the people who have spoken in the two days here. It has been very interesting and enlightening to me. I am a systems analyst, and as Deputy Director of the Center, I do not get deeply involved in these things too often.

But, I did have a question that I would like to pose. This morning, if I understood the speaker correctly, the activity seemed to increase in the presence of photochemical smog or the light and the things that are created in smog. These are some of the tests that were created in Los Angeles. Yet, I have heard much of the data presented here has come from experiments that have been performed in mines, where I guess you do not have the same conditions. Does anybody care to respond to that? What is the meaning? Am I missing something in terms of whether we just have a lack of a lot of data in understanding the whole subject of what happens in the outside air?

DR. THILLY: Well, from just the little bit that I have been able to learn about this crap that is on the outside, what some call the pure soot, the straight carbon, the graphitic parts, if it does not have a chance for photooxidation or mixture with nitrous oxide, of course, there is not going to be the formation of the peroxy polycyclics. You are not going to have an opportunity to form those wonderful nitro polycyclics that were discussed this morning. Of course, they are not going to be there.

On the other hand, this compound that we have dug up, this acepyrylene, if it does not get out into the sunlight for photooxidation, it is going to be in high concentration. I think you have to realize that these situations have to be analyzed. My point is that while it looked to us last year like it was a terribly complex problem, I think now with particularly GC-MS and HBLC systems, the problem can be cracked. You can identify and quantify 135 polycyclics under the most God-awful conditions in one day's work now. If you have a dictionary of their relative activity already, as we are compiling, in a number of different systems, you can then possibly take a look at your first approximation of risk simply by looking at your chemical analysis of what you got and multiply it out times what kind of activity you have for those particular compounds under any conditions, light, dark, down in a mine or after photooxidation.

DR. BLACKER: I would like also to comment on that. In the Cincinnati studies that EPA is conducting, we do expose the animals to both irradiated and non-irradiated diesel exhaust. The resonance time of the irradiated exhaust is something like three to five hours, depending on the flow rates that we run through.

We are very much aware of the problem you are raising, and we do try to design the experiments to measure both effects, to see whether there is a difference.

DR. KRAYBILL: I would like to ask Dr. Thilly a question. In one of your slides, I became interested in your information or data on perylene. I think I am familiar with that case you referred to about the salamanders down in Texas. Yet, we look in the book on perylene, and that seems to be a fairly weak or non-carcinogen. Yet, in your system, it seemed to show some activity. Would you care to elaborate on that?

DR. THILLY: I would like to wander in the field of data recently acquired, because, obviously, we had looked in all of the skin painting experiments and done a tox line and a cancer line search on perylene. It has generally been found to be inactive in skin painting tests, add there are no long term feeding tests in the literature nor long term exposures other than skin painting.

There is also something weird about perylene. If you notice the shape of the curve, it reached a saturation level at four micromolar. Benzo(a)pyrene does not even give any detectable activity at four micromolar,aadd yet, perylene had given a tremendous amount and then gave no more up to 400 micromole. We have gone up to several millimolar. It is a saturation curve. We

We have looked to see what was going on in terms of the metabolism. We varied the amount of oxygenation enzymes present. At reasonable levels like four micromolar, we find essentially that it saturates the metabolism at fairly low levels of the enzyme. But then Bruce Penman did some experiments in our lab. He kept going down from four micromolar to very low concentrations. He found that at a half a micromolar or one micromolar, I cannot remember exactly, that he got a maximum in terms of the presence of what we thought were the mixed function oxygenases.

I think what we have here, since I know it is active in this system, and I am talking about experiments that have been repeated about 10 times now, I know that it is active and I think that we are onto something weird in terms of the general mixed function oxygenase system. We are going to put whole cells into this system to find out what is going onl I think we ought to get ourselves some salamanders.

The fact is that there is something weird about perylene which allows one by having non-optimal mixed function oxygenation conditions, to just miss its activity or to observe no increase with concentration. Under those conditons, if you tested it at millimolar concentrations and saw low activity or some activity, you might just say well, at that concentration there is no effect. So, it might have been that it simply was not getting metabolized in mouse skin or some of the other things that we have to think about, whether it got in, whether it was metabolized, and to what was it metabolized. So, it is a real black box. I can only assure you that the data that we presented here has been done in the most professional way we can do it. We must now report its extreme activity.

DR. KRAYBILL: Thank you very much for that elaboration on that chemical. This explanation you gave today is very interesting.

Are there any other questions of the panel?

DR. MILLER: My name is Steve Miller, and I am a consultant. Now that everybody is getting tired and sleepy, maybe this is the appropriate time to throw out the question.

I would like to address each panelist and ask them, now that we have had this symposium and we have had EPA's Ames test results, I would like to ask where do we go next? What does each of you recommend in terms of further testing? What is the time frame in which we might be able to resolve the outstanding issues about diesel exhaust and the increasing dieselization of our automobile fleet?

Let us start with Stan Blacker and get the official EPA position.

DR. BLACKER: My quick comment to you is I will talk to you later and tell you what my speech was about, since you were not here, because every point that you asked for is somewhat discussed in it.

DR. VOSTAL: I completely agree with Dr. Blacker.

DR. THILLY: The MIT Department of Energy Laboratory is ready to discuss on a quid pro quo basis the production of appropriate analysis of the systems that you are interested in studying on a straight dollars for data arrangement.

DR. MILLER: Can I elaborate a little bit more. What I was asking for here is, in a sense, do we now go beyond the Ames test? Have we killed the Ames test? Have we studied enough bacteria with regard to diesel exhaust? Is it now time to go on to higher systems? Or is it time to go on to partially oxygenated substances, some of the nitro substances that Jim Pitts was able to find, combinations of substances in the Ames test? Where do we go? I mean we can keep studying the Ames test for the next seven, eight, nine, or ten years; and we still may not have resolution of the issue of what to do about diesel automobiles on the road and exposure. I raise this question to try to say something about iron oxide. One of the studies in a paper that Hans Falk recently gave at a task force that was dealing with a coal conversion that the President put together, there were some references to instillation studies where iron oxide was used as a co-carcinogen with benzo(a)pyrene and was found to be exceedingly active. I hate to use the word synergistic; but, indeed, it was synergistic.

Then you look at a recent paper in Science magazine about the effects of a number of heavy metals on heme synthesis and degradation, and you find that the cytochrome P450 system was severely altered in its nature with regard to its ability to do anything about some of the polynuclear aromatic hydrocarbons. So, my question is do we stay with the pure hydrocarbon in this very simple system, or do we move on? I was not trying to ask you the political question. I was trying to ask a research question of the panel members.

DR. THILLY: I would like to respond to a couple of points that were raised today about the way in which exposure is made to soot, which is quite different from a methylene chloride extract, a dimethyl sulfoxide extract, and so forth. It is a question of pharmacokinetics, and it is properly raised.

I understand from my associate, Tom Skopek, who is here today and was here yesterday, that something was brought up to us by carbon black producers. They felt that for some reason the polycyclics on the surface of the small particles, even though they are down there,in the lung and are going to be there for awhile, that somehow magically the adsorption of this stuff is so very strong. It is indeed strong. It is so strong that it will not come off in very mild kind of extractions. However, it does come off quite nicely in things like peanut oil. We have a very strong suspicion that it comes off very nicely. As was the case with some of the data today with the serum, particularly, you will find that proteins are extremely good at desorbing polycyclics. There are many serum-like proteins in this layer above the epithelial cells in the lung.

Furthermore, continuing along this line, there is the belief that somehow these little particles are being eaten up by macrophages,aadd macrophages go somewhere else. I am not a specialist on the lung, so I called up Professor Morrow at the University of Rochestertoo ask him about this when it was raised. He explained to me that it is, indeed, true that particles the size of bacteria, around a micron, are taken up primarily by the macrophages. But when you get below that size, we discovered that we are in a particle size range in which — I hope I have this right — endocytosis by the Type I and Type II epithelial cells of the lung is the primary means by which a particle itself leaves the lavageable surface of the lung; in other words, the space in the middle of the alveoli. As a result, I think we must now change this picture to these very small particles which, of course, have a very large surface area and then are going to be able to carry the polycyclics in greater mass per their own carbonaceous mass into the lung. They are simply going to be taken into what I understand to be the cell at risk in lung carcinoma. So, this hope that somehow we are going to be able to cough this stuff up with the macrophages or cough it up in aggregates may be a false hope; but that kind of research should be funded and should be carried out.

This is not a large program. We are talking about finding someone competent to do the work and to do the appropriate studies. There are so many things along this line that have to be done in a very careful manner, instead of in a wild charge of 75 different laboratories trying to do the same thing with one paper that has bee been published elsewhere.

DR. KRAYBILL: I suppose that is it. Thank you very much for your kind attention, and I thank the panelists again.

We are now adjourned.

DIESEL EMISSIONS WORKSHOP

April 27-28, 1978

Attendees

Private Sector

C. A. Amann
General Motors Research Labs
12 Mile and Mound Road
Warren, Michigan 48090

Jerar Andon
South Coast Technology, Inc.
P. O. Box 3265
Santa Barbara, California 93105

Dr. William D. Balgord
E & RT
P. O. Box 300
Brookfield, Connecticut 06804

E. G. Barry
Mobil Res and Dev Corp.
Research Department
Paulsboro, New Jersey 08066

Mario C. Battigelli
University of North Carolina
School of Medicine
Chapel Hill, North Carolina 27514

Mark H. Bauer
General Motors Corp.
GM Building
Detroit, Michigan 48002

R. J. Benner
Olds Division
Townsend Street
Lansing, Michigan 48933

Fred Bowditch
General Motors
GM Tech Center
Warren, Michigan 48033

William Chapman
General Motors
1660 L Street, N. W.
Washington, D. C. 20036

James F. Conte
EI I. Dupont
Petroleum Lab
Wilmington, Delaware 19801

Giorgio N. Cornetti
Fiat, S.p.A.
Via Del Drosso 145
10132 Torino, Italy

R. L. Courtney
Chevron Res. Co.
P. O. 1627
Richmond, California 94802

Dr. James P. Crowley
Battelle Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

D. L. Dimick
GM Tech Center
Engineering Staff
Warren, Michigan 48033

Klaus W. Drexl
Mercedes-Benz of N. A.
One Mercedes Drive
Montvale, New Jersey 07645

Charles J. Elder
GM Technical Center
Environmental Activities Staff
Warren, Michigan 48033

John H. Engel, Jr.
Chrysler Corporation
Highland Park
Detroit, Michigan 48206

Colin R. Ferguson
Purdue University
School of Mechanical Eng.
West Lafayette, Indiana 47907

Karl H. Faber
Mercedes-Benz of N. A.
One Mercedes Drive
Montvale, New Jersey 07645

Lester Forrest
The Aerospace Corporation
2350 El Segundo Blvd.
El Segundo, California 90245

Norman Friberg
Volvo of America Corp.
Rockleigh, New Jersey 07647

Robert Gibbons
Diesel Automobile Assn.
801 W. 181st
New York,NNew York 10033

Ann M. Gasier
American Mining Congress
1100 The Ring Bldg.
Washington, D. C. 20036

Alan J. Grobecker
National Science Foundation
800 G St., N. W.
Washington, D. C. 20550

J. C. Hafeley
Caterpillar Tractor Co.
100 NE Adams St.
Peoria, Illinois 61629

N. A. Henein
Wayne State University
Engineering Building
Detroit, Michigan 48202

Michael Henk
UOP Automotive Products Div
40 UOP Plaza
Des Plains, Illinois 60016

John T. Herridge
Battelle Columbus Labs
505 King Avenue
Columbus, Ohio 43201

Jon M. Heuss
GM Research Labs
GM Environmental Science Dept.
12 Mile and Mound Roads
Warren, Michigan 48090

Richard Hibbard
Delta Research Corp.
1401 Wilson Blvd.
Arlington, Virginia 22209

R. C. Holmquist
American Mining Congress
1100 Ring Building
Washington, D. C. 20036

Toru Iura
Aerospace Corporation
20030 Century Blvd.
Germantown, Maryland 20767

John H. Johnson
Michigan Technological University
Dept. of Mechanical Engineering
Houghton, Michigan 49931

Thomas C. Jones
Center for Auto Safety
1223 DuPont Circle Building
Washington, D. C. 20036

Victor Kebely
Aerospace Corp.
20030 Century Blvd.
Germantown, Maryland 20767

Brian Ketcham
Citizens for Clean Air, Inc.
32 Broadway
New York, New York 10004

Bernhard J. Kraus
Exxon Res. and Eng. Co.
P. O. Box 51
Linden, New Jersey 07036

Dr. H. F. Kraybill
National Cancer Institute
7910 Woodmont
Bethesda, Maryland 20014

Donald V. Lassiter
Environmental Health Assoc., Inc.
2510 Shattuck Avenue
Berkeley, California 94704

Bruno Lattore
Fiat S.p.A.
Fiat Centro Ricerche
Strada Torino 80
Orbassano, Italy

David Lax
Energy & Environmental Analysis, Inc.
1111 19th Street
Arlington, Virginia 22204

David G. Leddy
Dept. of Chemical Eng.
Michigan Technological University
Houghton, Michigan 49931

Philip L. Levins
Arthur D. Little, Inc.
Acorn Park
Cambridge, Massachusetts 02140

Dr. Lies
Volkswagenwerk AG
Wolfsburg
W. Germany

Phil Livingstone
Battelle
2030 M St., N. W.
Washington, D. C. 20036

Richard H. Lucki
Peugeot/USTR
33 Garland Way
Lyndhurst, New Jersey 07015

W. T. Lyu
Cummins Engine Co.
Columbus, Indiana 47201

D. Manca
IVECO
Via Puglia 35
10099 Torino
Italy

Peter V. Manteuffel
Daimler-Benz AG
Dept. ELV
7000 Stuttgart 60
W. Germany

Thomas Milby, M. D.
Environmental Health Assoc,, Inc.
524 Woodmont
Berkeley, California 94708

Stephen Miller
AVRAM Company
1010 Steeples Ct.
Falls Church, Virginia 22046

J. Ninomiya
Ford Motor Company
The American Road
Dearborn, Michigan 48126

Dr. Oetting
Volkswagenwerk AG
Wolfsburg
W. Germany

James E. Pasek
General Motors
1660 L Street, N. W.
Washington, D. C. 20036

Dr. James Pitts
SAPRC
University of California
Riverside, California 92521

Richard Pollak
Fusion Energy Foundation
GPO Box 1943
New York, New York 10001

James A. Richardon III
4551 LaSalle Avenue
Alexandria, Virgainia 22304

Rodger F. Ringham
Internationla Harvester Co.
1707 L Street, N. W.
Washington, D. C. 20036

David Rominger
Volkswagen of American
818 Sylvan Ave.
Englewood Cliffs, New Jersey 07632

Richard Schreck
GM Research Labs
Bio-Medical Science Dept.
Technical Center
Warren, Michigan 48090

A. B. Shuman
Mercedes-Benz of N. A.
One Mercedes Drive
Montvale, New Jersey 07645

Harold M. Siegel
South Coast Technology, Inc.
P. O. Box 3265
Santa Barbara, California 93105

Thomas R, Skopek
MIT Gen. Tox. Lab
40 Ames Street
Cambridge, Massachusetts 02139

A. J. Slechter
Ford Motor Company
815 Connecticut Avenue
Washington, D. C. 20006

Stephen A. Smaby
Mechanical Engineering Dept.
Michigan Tech. University
Houghton, Michigan 49931

Karl J. Springer
Southwest Research Institute
6220 Colebra Rd
San Antonio, Texas 78284

Bernard Stenhoff
Mercedes Benz
1 Mercedes Drive
Montvale, New Jersey 07645

Prof. William Thilly
MIT
Cambridge, Massachusetts 02139

Ivor Tombach
AeroVironment, Inc.
145 Vista Avenue
Pasadena, CAlifornia 91107

David W. Turner
Exxon Research
P. O. Box 51
Linden, New Jersey 07036

Karel A. Van Cauwenberghe
SAPRC University of California
Riverside, California 92521

Jaroslav J. Vostal, M. D.
GM Research Laboratory
Warren, Michigan 48090

Richard W. Wheeler
Ricardo Engineering
Shoreham-By-Sea
Sussex
England

Dr. Arthur M. Winer
SAPRC University of California
Riverside, California 92521

Mary Ann Zimmerman
Cummins Engine Co.
1000 - 5th Street
Columbus, Indiana 47201

Richard M. Klimisch
GM Tech Center
Engineering Staff
Warren, Michigan 48033

Government Agencies

R. W. Hurn
Department of Energy
P. O. Box 1398
Bartlesville, Oklahoma 74003

Douglas Baelim
U. S. Dept. of Energy
N. S. E 201
Washington, D. C. 20545

Dr. Jose L. Bascunana
DOT/NHTSA
Technology Assessment Division
Washington, D. C. 20590

William Basham
DOT/NHTSA
Technology Assessment Division
Washington, D. C. 20590

E. Karl Bastress
Depattment of Energ
10 Massachusetts Ave., N. W.
Washington, D. C. 20545

Ted Bayler
DOT/NHTSA
Washington, D. C. 20590

Jorgen W, Brikeland
Department of Energy
Division of Power Systems
Washington, D. C. 20545

Don Bischoff
DOT/NHTSA
400 Seventh St., S. W.
Washington, D. C. 20590

Stanley M. Blacker
Environmental Protection Agency
Waterside Mall
Washington, D. C. 20460

Glen Brammeier
DOT/NHTSA
400 Seventh St., S. W.
Washington, D. C. 20590

Dick Briceland
Environmental Protection Agency
400 M Street, S. W.
AW 444
Washington, D. C. 20460

John Brogan
Department of Energy
20 Massachusetts Ave., N. W.
Washington, D. C. 20545

Richard C. Carter
DOT/NHTSA
400 Seventh St., S. W.
Washington, D. C. 20590

Samuel C. Coroniti
U. S. DOT/OST
Washington, D. C. 20590

Roy Dennison
DOT/NHTSA
NEF-20
Washington, D. C. 20590

Richard D. Edsell
U. S. Dept. of Labor
Directorate of Technical Support
200 Constitution Avenue, N. W.
Washington, D. C. 20210

Vincent J. Esposito
Department of Energy
20 Massachusetts Ave., N. W.
Washington, D. C. 20545

Ralph Fleming
Department of Energy
20 Massachusetts Ave., N. W.
Washington, D. C. 20545

Herbert Gould
DOT/Transportation Systems Center
Kendall Square
Cambridge, Massachusetts 02142

Frank J. Hearl
Dept. of Health, Education & Welfare
944 Chestnut Ridge Road
Morgantown, W. Virginia 26505

Thomas A. Henrie
U. S. Dept. of Interior
2401 E Street, N. W.
Washington, D. C. 20241

Arthur J. Henry
DOT/NHTSA NRD-11
Room 3211 Transpoint Bldg.
Washington, D. C. 20590

Dan Hirsch
DOT/NHTSA/OAFES
400 Seventh St., S. W.
Washington, D. C. 20590

Robert Husted
DOT/OST/DPB-25
Washington, D. C. 20590

Homer Jackson
DOT/NHTSA
Washington, D. C. 20590

Kurt Jakobsen
U. S. Environmental Protection
Agency
RD-681
Washington, D. C. 20460

John P. Jankovich
DOT/NHTSA
Washington, D. C. 20590

Dr. Richard John
DOT/Transportation Systems Center
Kendall Square
Cambridge, Massachusetts 02142

Orron Kee
NHTSA NRM-22
400 Seventh St., S. W.
Washington, D. C. 20590

George Kittredge
US Environmental Protection Agency
401 M Street, S. W.
Washington, D. C. 20460

Merrill Korth
US Environmental Protection Agency
2565 Plymouth Road
Ann Arbor, Michigan 48105

Stephen Luchter
DOT/NHTSA NRM-22
Washington, D. C. 20590

Barry McNutt
U. S. Department of Energy
12th & Pennsylvania Ave., N. W.
Washington, D. C. 20461

John Machey
DOT/NHTSA NRM-22
Washington, D. C. 20590

Fred F. Marmo
DOT/Transportation Systems Center
Kendall Square
Cambridge, Massachusetts 02142

William Marshall
Department of Energy
P. O. Box 1398
Bartlesville, Oklahoma 74003

Robert A. Mercure
Department of Energy
20 Massachusetts Ave.
Washington, D. C. 20545

John N. Murphy
Department of the Interior
Bureau of Mines
4800 Forbes Avenue
Pittsburgh, Pennsylvania 15213

Joseph L. Patrick
Department of the Interior
Bureau of Mines
2401 E Street
Columbia Plaza
Washington, D. C. 20241

Samuel F. Powel,III
DOT/NHTSA
Technology Assessment Division
Washington, D. C. 20590
NRD-13

Frank Princiotta
US Environmental Protection Agency
401 M Street, S. W.
Washington, D. C. 20460

Douglas Pritchard
DOT/NHTSA
NRM 23
Washington, D. C. 20590

Stanley Scheiner
DOT/NHTSA
NRM-22
Washington, D. C. 20590

Alan L. Silverstein
US ENvironmental Protection Agency
Mobile Source Enforcement Div. (EN-340)
401 M Street, S. W.
Washington, D. C. 20460

Joe Somers
UA Environmental Protection Agency
2565 Plymouth Road
Ann Arbor, Michigan 48105

Dr. R. L. Strombotne
DOT/NHTSA
NRM-20
Office of Automotive Fuel
Economy Standards
Washington, D. C. 20590

Joe Sturm
U. S. DOT/TSC
Kendall Square
Cambridge, Massachusetts 02142

George Thur
Department of Energy
20 Massachusetts Ave.
Washington, D. C. 20545

Dr. Leonard Topper
Office of Energy Research
Department of Energy
20 Massachusetts Avenue, N. W.
Washington, D. C. 20545

Tom Trells
DOT/TSC
Kendall Square
Cambridge, Massachusetts 02142

Robert K. Whitford
DOT/TSC
Kendall Square
Cambridge, Massachusetts 02142

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